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GEOLOGY OF NEW SOUTH WALES

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AN INTRODUCTION
TO THE
GEOLOGY OF NEW SOUTH WALES

BY

C. A. SÜSSMILCH, F.G.S.

PRINCIPAL OF NEWCASTLE TECHNICAL COLLEGE, LATE LECTURER IN CHARGE OF THE
DEPARTMENT OF GEOLOGY AND MINING, SYDNEY TECHNICAL COLLEGE

*Second edition, revised and enlarged,
with 100 illustrations and maps*

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To

PROFESSOR T. W. EDGEWORTH DAVID, B.A., D.Sc.,
F.R.S., C.M.G.,

TO WHOM WE OWE SO MUCH OF OUR KNOWLEDGE
OF THE GEOLOGY OF NEW SOUTH WALES

PREFACE

THIS compilation of our present knowledge of the Geology of New South Wales has been prepared primarily for the use of students; it will also, it is hoped, be of some use to teachers, mining men and others. The information has been condensed as much as possible, so that the size of the book may be kept within limits enabling it to be published at a price within the reach of all students.

Such a compilation has long been needed, as no connected account of the Geology of this State has appeared since that published by the late C. S. Wilkinson in 1882, which has long been out of print. Many important contributions have been made to our knowledge since Wilkinson's work was published; but, scattered as they are through various official and other publications, some of which have been published abroad, while others are out of print, the information they contain is not accessible to the majority of students.

In the preparation of these pages the writer has gathered his facts from many sources. Full use has been made of the many excellent monographs, reports, &c., published by the Mines Department of New South Wales, and from these many of the geological sections and illustrations of fossils have been taken. The various geological papers which have appeared from time to time in the Proceedings of the Royal Society of New South Wales, in the Proceedings of the Linnean Society of New South Wales, and in the Memoirs of the Australian Museum, have also been largely drawn upon. The geological workers whose papers have been made use of include, among others, E. C. Andrews, W. N. Benson, G. W. Card, J. E. Carne, Rev. W. B. Clarke, Professor T. W. E. David, Hy. Deane, W. S. Dunn, R. Etheridge, Junr., L. F. Harper, J. B. Jaquet, Dr. H. I. Jensen, Dr. D. Mawson, E. F. Pittman, C. S. Wilkinson, Rev. Tenison Woods, and Dr. W. G. Woolnough.

Even now, notwithstanding the many important additions to the Geology of New South Wales made during the past twenty-five years, our knowledge of it is still very incomplete; many blanks exist, many problems await solution. The area to be covered is large, while the workers are few; so that it will be many years before anything even approaching a complete account of the geological history of this State will be possible. Meanwhile, besides supplying the immediate need for a student's text-book, it is hoped that this compilation will be serving a useful purpose in "taking stock" of our present knowledge—in showing how much has already been accomplished, how much still remains to be done.

The classification of the geological formations here used is, with some slight modifications, that adopted by Mr. E. F. Pittman in his "Epitome of the Geology of New South Wales," published in 1909, and to him my hearty thanks are due for permission to reproduce many of the geological sections and illustrations of fossils which have appeared in the publications of the Mines Department. Some few of the fossil illustrations have been copied from the Memoirs of the Australian Museum, and for permission to use these my thanks are due to Mr. R. Etheridge, junr. To Dr. W. G. Woolnough my thanks are due for the photograph and section at Tallong (Figures 3 and 4), and to Dr. D. Mawson for information regarding the Broken Hill District. I am much indebted to Mr. W. S. Dun for reading through and correcting the lists of fossils, and for much kind assistance; and my hearty thanks are also due to Professor T. W. E. David and Messrs. E. C. Andrews, G. W. Card, J. E. Carne, and R. Etheridge, junr. for much kindly advice and assistance.

A glossary of the less common geological terms used in the book has been included.

Newcastle Technical College,
April, 1914.

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GEOLOGY OF NEW SOUTH WALES



CHAPTER I.

INTRODUCTION.

THE earliest connected account of the Geology of New South Wales is that written by the late Rev. W. B. Clarke, and published by him in 1867, entitled "Remarks on the Sedimentary Formations of New South Wales"; later editions of this work appeared in 1870, 1875, and 1878. This great worker, the pioneer of the geologists of this State, laboured for many years, practically singlehanded, in a thinly-populated area of vast extent, and established the succession of the sedimentary formations of New South Wales. Upon the foundations so ably laid by him the superstructure of our present knowledge of its geological history has been erected. Considering the adverse circumstances under which he laboured, it is surprising how well these foundations have stood the test of time, and they stand to-day as an enduring record of his great ability and the patient care with which he applied himself to his work.

In 1882 the late C. S. Wilkinson, F.G.S., F.L.S., then Government Geologist, published his "Notes on the Geology of New South Wales"; in this he summarised the information then available. He, too, was an able pioneer and great worker, who thought nothing of making long journeys through the sparsely-settled interior, where travelling was of the roughest and

means of communication few. He added notably to our knowledge, and was a worthy successor to Clarke.

Since 1882 many able geologists have added largely to our store of knowledge, but, except for an epitome published in 1909 by Mr. E. F. Pittman, Government Geologist, no connected account of the geology of this State has since appeared.

The main features of the geological history of New South Wales are now well established, but much additional field-work must be undertaken before anything like a complete record will be available. This applies particularly to the pre-Cambrian and Lower Palæozoic periods, our knowledge of which is still very incomplete.

The order of succession of the sedimentary formations of New South Wales is given in tabular form on page 5. An examination of this will show that nearly all the main subdivisions of the geological record of the northern hemisphere are represented, and that the same names are, in general, used for them. It must, however, be remembered that it is not by any means certain that formations which carry similar names in Australia and Europe were actually contemporaneous; in fact, some Australian geologists go so far as to suggest that purely local names should be used for the subdivisions of the great eras in Australia.

Pre-Cambrian formations appear to be but poorly represented, and occur over but limited areas, while the Cambrian has an even more limited development.

The other divisions of the Lower Palaeozoic era, viz. the Ordovician, Silurian, and Devonian, occur, however, more or less over the whole State, although concealed to a considerable extent in some regions by younger formations. The Upper Palaeozoic formations are less widely distributed, being confined to the central and northern tableland areas. The Mesozoic era is represented by fresh-water Trias and Trias-Jura strata and by Cretaceous Marine strata, but their development is in nowise comparable with that of the Palaeozoic formations either in thickness or extent. Tertiary formations are still more poorly represented. Marine strata are practically absent, while fresh-water deposits are limited to those occurring along Tertiary stream channels; Tertiary lava flows are, however, abundant and widespread. The direct geological records of the Tertiary history of New South Wales are, in fact, so scanty that, were it not for the evidence provided by a study of the development of its physiography, our knowledge would be limited indeed. Fortunately the topography has recorded a very legible and interesting history, which will be dealt with more fully in a later chapter.

Orogenic earth movements are recorded for the pre-Cambrian and Palaeozoic eras only; the most important crustal movements of this class appear to have taken place (1) at the close of the pre-Cambrian, (2) at the close of the Ordovician, (3) at the close of the Devonian periods; and in addition (4) at the close of the Carboniferous and Permo-Carboniferous

periods in the north-eastern part of the State. The crustal movements of the Mesozoic and Cainozoic eras were of the epeirogenic type, in which vertical uplift was the dominant feature.

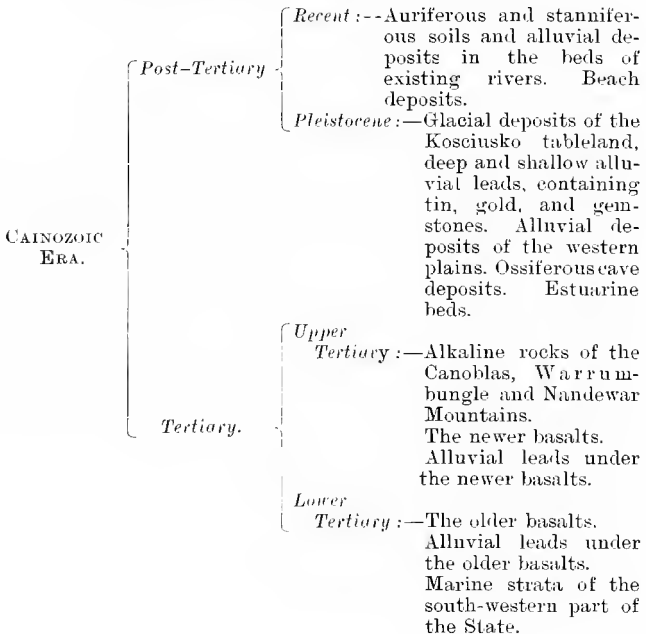
The succession of animals and plants has been, on the whole, essentially similar to that of other parts of the world; there are, however, some striking differences, particularly in the life of the land. The marine faunas of the various sub-divisions of the Palæozoic era and of the Cretaceous period resemble fairly closely those of the northern hemisphere, some of the species even being identical. In its terrestrial faunas, however, New South Wales, in common with the rest of Australia, shows some remarkable features. That extraordinary group of terrestrial reptiles which dominated the Mesozoic land life of Europe and North America is conspicuously absent, the only vertebrates known to have lived during this era being fish and amphibia; and many of these were akin to Palæozoic types of the Northern Hemisphere. Again, placental mammals, either as fossils or as indigenous living animals, except for the Dingo and certain native rats, are entirely absent from Australia; on the other hand the non-placental mammals (Monotremes and Marsupials), which first appeared during the Tertiary period, have since developed on a scale unknown in any other part of the world.

The fossil floras, too, possessed characters of their own; the Permo-Carboniferous flora (Glossopteris flora), for example, while identical with that of the same period in India and South Africa, has no

counterpart in the Carboniferous or Permian floras of Europe and North America.

The mineral wealth of New South Wales is considerable, the output for the year 1913 being valued at about £12,100,000 sterling, while the total production to date exceeds £241,000,000 in value. The more important substances mined include coal, copper, gold, silver, lead, zinc, tin, and precious stones.

ORDER OF SUCCESSION OF THE SEDIMENTARY
FORMATIONS OF NEW SOUTH WALES.



INTRODUCTION

ORDER OF SUCCESSION OF THE SEDIMENTARY FORMATIONS
OF NEW SOUTH WALES—(continued).

MESOZOIC ERA.	Cretaceous.	Upper Cretaceous:—	Desert sandstone formation.
		Lower Cretaceous:—	Rolling-downs formation.
	Trias-Jura.	Clarence series, Artesian series, Talbragar beds.	
PALÆOZOIC ERA.	Triassic.	Hawkesbury series.	Wianamatta shales.
			Hawkesbury sandstone.
			(Narrabeen beds.
PALÆOZOIC ERA.	Permo-Carboniferous	Upper coal-measures.	
		Dempsey series.	
		Middle or Tomago coal-measures.	
		Upper Marine series.	
		Lower or Greta coal-measures.	
	Carboniferous	Lower Marine series.	
		Upper Carboniferous — Rhacopteris beds and associated Marine beds.	
	Devonian.	Lower Carboniferous.	
		Upper Devonian (Lambian), Mount Lambie, Molong and Yalwal beds.	
		Lower Devonian (Murrumbidgean), Murrumbidgee beds and Tamworth beds.	
Silurian.	Limestones and Claystones at Yass, Molong, Orange, Jenolan, Wellington, &c.		
Ordovician.	Graptolite slates of Cadia, Tomingly, Mandurama, Tallong, Berridale, &c.		
Cambrian.	Glacial beds, limestones, &c., of the Barrier district.		
PROTEROZOIC AND ARCHÆOZOIC ERAS.	Pre-Cambrian.	Metamorphic series of the Broken Hill and Cooma districts.	

CHAPTER II.

PHYSICAL GEOGRAPHY.

NEW SOUTH WALES, from a geographical point of view, consists of two portions—(a) The Highlands; (b) The Western Plains.

(a) THE HIGHLANDS.

These consist of a series of tablelands, occupying the whole of the eastern part of the State, and extending from the coast inland for a distance of from 150 to 200 miles. They thus form a broad belt parallel to the coast, and are continuous with the highlands of Victoria and Queensland. These tablelands resulted from the uplift of a peneplain at the close of the Tertiary period to altitudes varying from a few hundred up to 6,000 feet, but averaging about 2,000 feet. This differential uplift was accompanied by faulting and warping, as a result of which the plateau region now consists of a series of more or less rectangular blocks (fault-blocks) separated from one another in many cases by abrupt differences of elevation. This tableland region in its central portions is more or less flat-topped, but its margins are flexed downwards towards the coast on the one hand and towards the western plains on the other. On both its eastern and western margins the plateau region has suffered considerable dissection by stream

action since its uplift. Extensive flood plains have been developed along the lower courses of the eastern rivers, and these are sometimes referred to as coastal plains; similarly where the western streams approach the western plains the tablelands have been much dissected, and extensive alluviation marks the entry of these streams on to the plains.

The highlands may, for convenience, be divided into three portions:—

1. The Northern or New England Tableland.
2. The Central Tableland.
3. The Southern or Monaro Tableland.

1. *The Northern or New England Tableland.*—This extends from the Queensland border southwards to the Hunter River district; here the Hunter River, cutting its valley westward into the main divide, and the Peel River heading eastward, have nearly breached the divide, a low ridge only remaining as a connection between the northern and central tablelands. This breaching of the highlands at this point is due partly to unequal uplift accompanied by faulting. The northern tableland is built up, very largely, of Palaeozoic formations; but in the north-eastern corner, and along the western margin, these rocks are overlain by Trias-Jura freshwater beds. Tertiary basalt flows occur over considerable areas. The general altitude of this tableland is about 3,300 feet, but some of the fault-blocks, such as those at Guy Fawkes and Guyra, rise to altitudes of from 4,000 to 5,000 feet.

2. *The Central Tableland.*—The northern margin of this section has already been referred to. It is bounded on the south by the Yass tableland, a relatively low fault-block (1,700 to 2,000 feet in altitude) which lies between it and the Monaro tableland. The altitude of the central tableland varies; the Bowral-Moss Vale portion has an altitude of about 2,000 feet, the Wombeyan portion about 3,000 feet, the Blue Mountain portion varies from 700 to 4,000 feet with a decided warp eastwards, the Orange-Blayney portion about 3,000 feet, while the Sydney Senkungsfeld in its lowest portion is not much above sea-level. The western and south-western parts of this tableland are built up of Palæozoic rocks, but its eastern and northern portions are occupied by the Permo-Carboniferous-Triassic basin.

3. *The Southern Tableland.*—This occupies the south-eastern part of the State, and includes the highest land in Australia. It is a composite tableland, consisting of a group of fault-blocks ranging from 2,000 to 7,000 feet in altitude, and separated from one another by great fault escarpments. Some of the lower blocks are sandwiched in between higher blocks in such a way as to form typical “rift valleys” or senkungsfelder. The whole of this region is occupied by pre-Cambrian and Lower Palæozoic rocks, except for a capping of Permo-Carboniferous strata over a limited area in its north-eastern portion. Extensive Tertiary basalt-flows cap the tableland in some localities.

(b) THE WESTERN PLAINS.

These extend from the western edge of the eastern highlands to the South Australian border; they consist partly of low flat-topped plateaux and partly of alluvial plains, and nowhere have an altitude greater than 1,000 feet. Occasional isolated hills rise above the level of the plains, but these are few and far between. The low plateau portion forms a broad belt extending from the western edge of the central tableland in a westerly and north-westerly direction to the Darling River, and from thence to the South Australian border; its surface is a peneplain cut out of Lower Palaeozoic strata. For this area the term central-western tableland may be used in order to distinguish between it and the alluvial plains to the north and south. The general altitude of its surface ranges from 600 to 900 feet. To the north of this lie the "Black-soil Plains," which consist of alluvium deposited by the Darling River, and its tributaries during flood-time; these alluvial deposits overlie the Cretaceous and Trias-Jura strata which form the artesian basin of New South Wales. South of the low plateau belt and along the lower courses of the Murray, Murrumbidgee, Lachlan, and Darling Rivers, lie the Riverina Plains; here also the surface is occupied by alluvial deposits, the waste of the southern tablelands brought down and deposited by rivers during floods. These alluviums overlie Lower Palaeozoic strata, except in the south-western corner, where they overlie Tertiary marine beds. The rainfall over the western plains is small, varying from 20 inches

to less than 10 inches; over the tablelands, on the other hand, the rainfall ranges from 20 to 70 inches per annum.

(c) THE RIVER SYSTEMS.

As the main divide of New South Wales runs approximately north and south, the rivers fall naturally into two groups—(1) the eastern rivers; (2) the western rivers; and as the main divide is relatively near the eastern coast, the eastern rivers are correspondingly short, while the western streams are much longer.

1. *The Eastern Rivers.*—As these have relatively short courses and a high grade they are, for the most part, rapidly flowing streams, subject to severe floods. Some of them, like the Hunter River, flow in more or less direct courses to the sea; others, like the Hawkesbury River, have their main course parallel to the coast for 100 miles or more. In nearly all cases there is abundant evidence that the latter are revived or rejuvenated streams, and existed before the uplift which produced the existing highlands took place. Throughout the greater part of their courses they are entrenched in deep canyons.

2. *The Western Rivers.*—These may be divided into two groups—a northern one, which includes the Upper Darling River and its tributaries, and a southern group, the Murray and its tributaries, the Murrumbidgee and Lachlan Rivers. Many of the northern group, such as the Macquarie, Bogan, &c., flow in a

general north-westerly direction until they join the Darling River. They probably originated during the Cretaceous Period and flowed then as individual streams to the south-eastern margin of the Cretaceous sea. Some of these tributaries of the Darling, for example the Macquarie, fail to reach it except in flood-time, usually dying away in marshes and swamps. The Murray River, like its tributaries the Murrumbidgee and Lachlan Rivers, flows in a general westerly direction to the South Australian border, where it suddenly turns southward and empties into the Southern Ocean.

CHAPTER III.

PRE-CAMBRIAN FORMATIONS.

Very little is known at present of the occurrence of pre-Cambrian rocks in New South Wales; and, as the greater part of the State has now been mapped in some detail, it is fairly certain that the areas over which such rocks might occur must be limited in extent. There are, however, two districts in which pre-Cambrian rocks are believed to occur, viz., the Barrier district and the Cooma-Kosciusko district.

The Barrier District.—This is in the western part of New South Wales, adjacent to the South Australian border, with the town of Broken Hill as its chief centre. The rich silver-lead-zinc deposits of this region have made it world famous. The oldest undoubted sedimentary strata occurring here are of Cambrian age, and will be described in the next chapter; associated with these there is an older metamorphic series of undoubted pre-Cambrian age known as the Willyama series. This series includes gneisses, schists, quartz-garnet rocks, amphibolites and phyllites; garnet is a common constituent of many of these rocks, while the schists include mica-schists, sillimanite-schists, talc-schists, and chlorite-schists. The origin of this metamorphic series has not yet been satisfactorily determined, but the balance of evidence appears to favour the view that many of them repre-

sent highly altered sedimentary rocks. The schists, both from their mode of occurrence and composition appear for the most part to be highly altered sedimentary rocks. The origin of the gneisses is more doubtful; some appear to have resulted from the alteration of the pre-Cambrian granites; some are possibly of the kind known as injection gneisses—that is, they have been injected in the form of thin layers between the layers of the schists. On the other hand, gradations between quartzites and quartz-felspar rocks suggest that at least some of the gneisses have resulted from the extreme alteration of sedimentary rocks. It has been suggested that the amphibolites are intrusive dykes forced upwards along the bedding planes of the sedimentary rocks before they were metamorphosed; but the description of their occurrence suggests that some of them may be highly metamorphosed basic lavas and tuffs.

Numerous bosses and batholiths of muscovite-biotite-granite intrude the metamorphic series; these are also of pre-Cambrian age, for they do not intrude the Cambrian rocks of the district, while waterworn boulders of them occur in the Cambrian basal beds. A marked feature of these intrusions was the formation of an abundance of pegmatite veins which intrude the metamorphic series in all directions.

Rocks of the Willyama series outcrop over an area about 20 miles long in a north and south direction, and about 30 miles wide; they are unconformable with the Cambrian rocks above referred to (see Fig. 2).

Associated with this metamorphic series there

occurs one of the richest of the world's ore deposits, some idea of the value of which may be gathered from the fact that during the twenty-five years which have elapsed since mining was first started £70,000,000 worth of metals have been produced, and over £13,000,000 have been paid in bonuses and dividends. This deposit is being worked for a distance of 3 miles along its strike, and to a depth of 1,600 feet below the outcrop, and at some places to a width of upwards of 400 feet. The true origin of this mammoth ore deposit is still in dispute; some regard it as being a saddle-reef, analogous to those of the Bendigo Goldfield, while others regard it as having been produced by the metasomatic replacement of the country rock along a zone of shearing and crushing (shear-zone). The latter view is the more probable.

The original sulphide ore consists of an intimate mixture of argentiferous-galena and zinc-blende, with smaller amounts of quartz, garnet, fluorite, felspar rhodonite, pyrite, and chalcopyrite; it contains from 5 to 36 oz. of silver, from 5 to 50 per cent. of lead, from 14 to 30 per cent. of zinc, and from 2 to 3 dwt. of gold per ton. The oxidised zone was very rich in carbonate of lead, chloro-bromides of silver, and native silver. The value of this ore ranged up to 300 oz. of silver and 60 per cent. of lead per ton.

Cooma-Kosciusko Region.—In the neighbourhood of Cooma there occurs an extensive series of metamorphic rocks, including gneisses, mica-schists, phyllites, and amphibolites; in the same area there also occur the fossiliferous Ordovician strata referred to

on page 24. The field relations of these two series of strata have not yet been investigated; but as the latter have suffered very little metamorphism, while the former are strongly metamorphosed, it seems probable that the former must be considerably older than the Ordovician beds. The view has been put forward recently that there is an unbroken succession from the metamorphic series to the graptolite beds, and that the former are merely a metamorphosed phase of the latter. If this view should prove to be correct, then this metamorphic series is of Ordovician age. The metamorphic series, in its lithological characters, much resembles the pre-Cambrian formations of other parts of Australia, and may, therefore, be provisionally classed with them. Near Cooma the gneisses contain numerous veins of pegmatite, in some of which the mineral tourmaline is abundant; they have associated with them also irregular masses of amphibolite. The schists and phyllites are very much contorted, and show every evidence of having been subjected to extreme metamorphic influences.

Somewhat similar gneisses and phyllites occur on the Kosciusko Tableland.

Albury District.—An extensive series of metamorphic rocks occurs in the district around the town of Albury; these are no doubt an extension of the Mitta Mitta series of the adjoining State of Victoria, where they are considered to be of pre-Ordovician age, and may provisionally be placed here. These rocks lithologically resemble the Cooma series.

CHAPTER IV.

CAMBRIAN PERIOD.

No strata containing Cambrian fossils have yet been found in New South Wales, but Mr. D. Mawson, D.Se., has recently shown that certain strata in the Barrier District are lithologically the same as the Cambrian strata of South Australia, and are continuous with them. They outcrop at Torrowangee, about 20 miles from Broken Hill, and include slates, quartzites, limestones, dolomitic-limestones, and glacial boulder-beds (tillite). This series is unconformable with the pre-Cambrian metamorphic series of Broken Hill. The glacial boulder-beds, which occur at the base of the series, consist of a fine-grained quartzitic matrix (sometimes argillaceous), in which are embedded boulders of granite, gneiss, quartzite, schist, and slate, varying in size from a few inches up to two feet in diameter; it ranges up to 800 feet in thickness.

Interstratified with the glacial boulder beds are quartzites, grits, laminated slates and limestones. One of these limestone beds was quarried at Torrowangee for use as a flux, when smelting was being carried on at Broken Hill. This bed is believed to be the equivalent of the Brighton limestone of the Mount Lofty series of South Australia, shown in the section in Fig. 1. The Cambrian limestones have been much metamorphosed and are more in the nature of true marbles.

A generalised section of these Cambrian strata in South Australia (as drawn by the Rev. W. Howchin, F.G.S.) is given in Fig. 1. They will be seen to consist of conglomerates, limestones, quartzites, slates, and glacial beds, the whole series resting unconformably upon a pre-Cambrian metamorphic series. The beds described as having a glacial origin consist mainly of unstratified, indurated mudstone, more or less gritty, and carrying angular, subangular, and rounded boulders, which are irregularly distributed through the mass; these boulders range up to 11 feet in diameter. Most of the large erratics consist of quartzite, but granite, gneiss, porphyry, and schist erratics also occur; many of these boulders are ice-scratched and faceted. These boulder-beds are regularly interstratified with the Cambrian sediments, and do not rest upon a glaciated land surface; they are, therefore, not typical moraine-deposits. Nevertheless, much of the material in these beds has undoubtedly had its origin in terrestrial glaciers, and was transported to its present position by floating ice. The position of the Cambrian land which supported the glaciers is not definitely known, but appears to have been to the south-west of the present glacial beds. The glaciers must have reached sea-level, and, as happens in Antarctica to-day, large masses of ice must have broken away from time to time, and floated northwards across the Cambrian Sea; as this ice melted, its load of morainic material would be strewn over the sea-bottom.

This glacial horizon occurs at the base of the Cam-

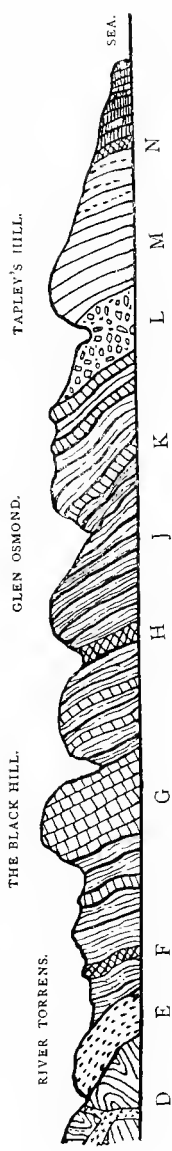


Fig. 1.

Diagrammatic section of the Lower Cambrian Beds, Mount Lofty Ranges, South Australia (Howchin).

D = Pre-Cambrian. E = Basil grits and conglomerates. F = Lower limestone. G = Quartzites. H = "Blue-metal" limestone. J = Slates. K = Glen Osmond quartzite. L = Glacial beds. M = Tapley's Hill shales. N = Brighton limestones.

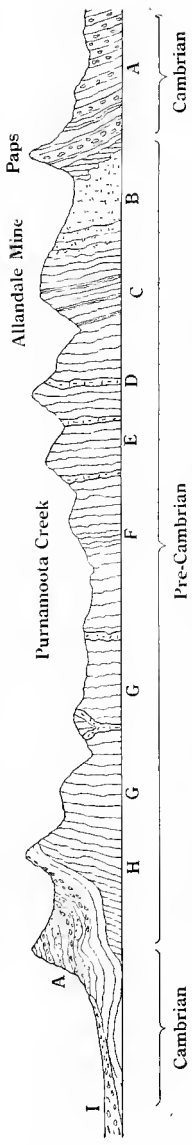


Fig. 2.

Sketch section of Cambrian and Pre-Cambrian Strata near Broken Hill, N.S.W. (Mawson).

brian formation of the Barrier District in New South Wales, and the lower strata shown in the South Australian section in Fig. 1 are absent; the Barrier District must, therefore, have been dry land during the earlier part of the Cambrian period.

The limestone beds of South Australia are numerous, and range up to several hundreds of feet in thickness; some of them are dolomitic in composition. Only two of them are known to contain fossils, and, of these, the most important is that containing *Archæocyathinæ*. These organisms, although not true corals, built extensive reefs in the Cambrian seas, not unlike the coral-reefs of the present day. The same limestone contains numerous other fossil invertebrates, such as Sponges, Trilobites, Brachiopods, Gasteropods, and Pteropods. The other fossiliferous horizon occurs about 1,000 feet vertically above the *Archæocyathinæ* limestone, and is stratigraphically above the glacial beds; it contains Trilobites, Brachiopods, and Pteropods. As already mentioned, no fossils have yet been obtained from the Cambrian strata in New South Wales, but as it is probable that life in the Cambrian seas of New South Wales was essentially the same as in South Australia, the following list of Cambrian fossils from the neighbouring part of the latter State may be taken as representing the Cambrian fauna:—

Archæocyathinæ. — *Archæocyathus*, *Coscinocyathus*.

Porifera.—*Hyalostelia*.

Brachiopoda.—*Orthisina*, *Orthis* (?), *Obolella*.

Pelecypoda.—*Ambonychia*.

Gasteropoda.—*Stenotheca*, *Platyceras*, *Ophileta*.

Pteropoda.—*Sallerella*, *Hyalithes*.

Trilobita.—*Olenellus*, *Microdiscus*, *Conocephalites*,
Ptychoparia, *Dolichometopus*.

Crustacea (Ostracods).—*Leperditia*.

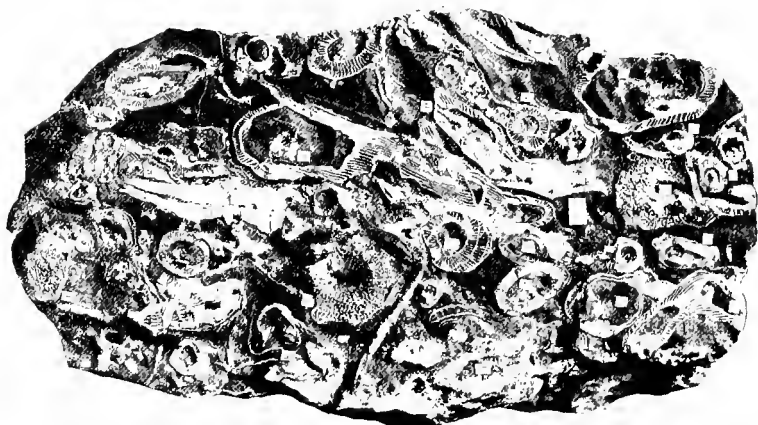


Fig. 3.

Archæocyathinæ Limestone, from Ajax Hill, Beltana, South Australia.

An etched specimen showing the fossils in relief. (After Taylor.)

THE ARCHÆOCYATHINÆ.—These anomalous organisms have the outward form of Sponges, but in their more detailed structures they resemble corals. (See Fig. 3.) They have been referred by different palæontologists to the Algæ, the Sponges, and the Corals; it has also been suggested that they are the ancestors

of both the Corals and the calcareous Sponges. Whatever their true nature, they flourished in enormous numbers in the Cambrian Seas, occupying in importance the position later taken by the reef-building Corals.

BRACHIOPODS.—These belong to small primitive types.

MOLLUSCA.—The Gasteropods and Pteropods are most in evidence; the former belong chiefly to the primitive uncoiled conical types (capulids).

CRUSTACEA.—Trilobites were abundant, and were the most distinctive and highly organised denizens of the Cambrian Sea; of the genera listed above *Olenellus* is perhaps the most characteristic. Small Ostracods, which had their bodies protected by valve-like shells resembling those of the bivalve molluscs, also occurred in considerable numbers.

CHAPTER V.

THE ORDOVICIAN PERIOD.

THE occurrence of Ordovician strata in New South Wales was unknown as recently as 1896, when Mr. J. E. Carne discovered Ordovician graptolites in the counties of Auckland and Wellesley, near the Victorian border. Since then similar graptolite-bearing strata have been found at many widely separate localities on the southern and central tablelands, as far north as Tomingley. The known occurrences apparently lie on several well-defined north and south axial lines.

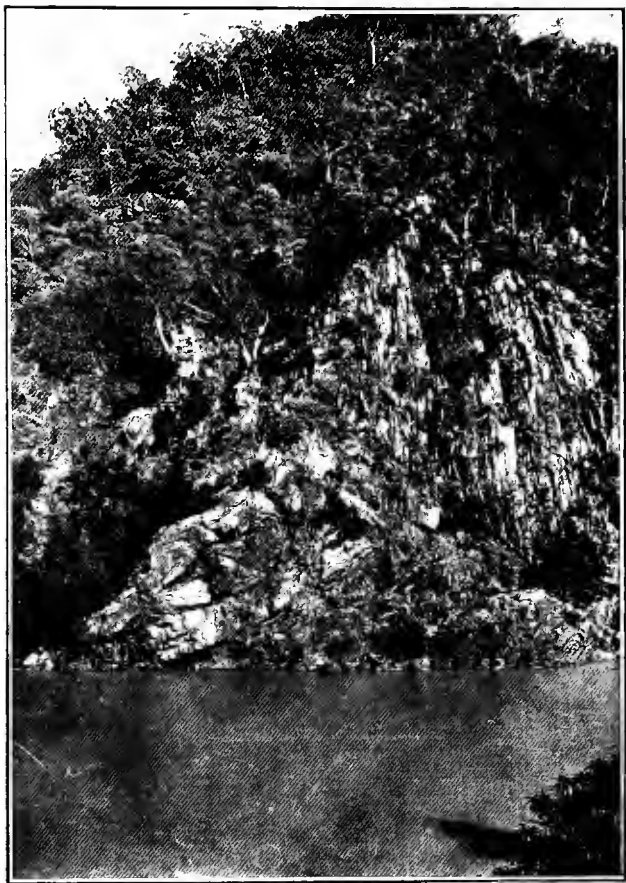
The repeated discovery of Ordovician graptolites in strata previously believed to be of Silurian age makes it probable that they may be found in many other parts of the State, and thus very much extend the known Ordovician areas. The lithological characters of some of the so-called Silurian strata presents considerable similarity, so that the determination of the age of either strata on any other than a palæontological basis is practically impossible.

Counties of Auckland and Wellesley.—The strata here consist of carbonaceous shales, claystones, sandstones, and schists striking nearly north and south, and outcropping at intervals along the southern border of New South Wales from Cape Howe to the headwaters of the Murray River. These beds are, no doubt, an

extension of the well-known Ordovician strata of the adjoining State of Victoria. Graptolites occur in abundance in the carbonaceous shales. Auriferous quartz reefs intersect the strata in many places and have been mined to some extent. Similar graptolite beds occur at Berridale, and also in the neighbourhood of Cooma; at the former they contain radiolaria.

Tallong.—A thick series of Ordovician strata outcrops on the Razorback, a spur between Barber's Creek and Shoalhaven River. (Fig. 4.) They consist of carbonaceous shales, slates, and quartzites, all of which are intensely folded and crumpled. The first-named contain numerous well-preserved graptolites. Silurian strata can here be seen resting upon the Ordovician beds, and are separated from them by a well-marked unconformity. (Fig. 5.) The mineral deposits at Tolwong, some few miles to the south, occur in strata of similar age.

Lyndhurst Gold-field.—At Mandurama the Ordovician formation consists of claystones with interbedded tuffs and thin bands of radiolarian limestones, the whole occurrence bearing a remarkable resemblance to the radiolarian beds of the Tamworth district. The Tamworth beds are, however, of Lower Devonian age. The Mandurama claystones contain graptolites, brachiopods (*Obolella*), and doubtful trilobites (? *Agnostus*). The whole series has been intruded by dykes and sills of diorite and augite-andesite, and where these occur the porous submarine tuffs have become impregnated with auriferous quartz, calcite,



[Photo, by W. G. Woolnough, D.Sc.]

Fig. 4.

Ordovician Strata, Shoalhaven River, near Tallong, New South Wales.

mispickel, and pyrite. These deposits have been mined for gold.

Cadia District.—At Cadia, near Orange, typical graptolite-bearing carbonaceous shales occur, associated with claystones, sandstones, and andesite tuffs. The largest iron ore deposit known in New South Wales occurs associated with these strata. This bed, which is about 60 feet thick (Fig. 6), lies between two sheets of andesite, and has been estimated to contain at least 40,000,000 tons of iron ore. Much of this ore, however, contains objectionable quantities of copper and sulphur. Gold and copper deposits also occur in this region.

The iron ore deposits at Carcoar, some distance to the south of Cadia, are also believed to occur in the Ordovician strata; iron ore from this locality is being smelted at Lithgow. The iron ore deposits of Carcoar and Cadia appear to have been produced by the alteration of pyritic ore bodies.

Parkes-Forbes District.—Rocks of definite Silurian age occur in this district, but the non-fossiliferous belt of strata in which the gold reefs occur appears to be a much more highly altered series, and to be pre-Silurian in age. They strike from north to N. 15° E. and have been traced from the Lachlan River northwards for a distance of about 32 miles. At Tomingley, about 30 miles still further to the north, similar strata have yielded Ordovician graptolites. The sediments of the auriferous belt in the Forbes-Parkes district are very thick, and consist of a mass of folded schistose slate, arenaceous claystones, limestones, breccias

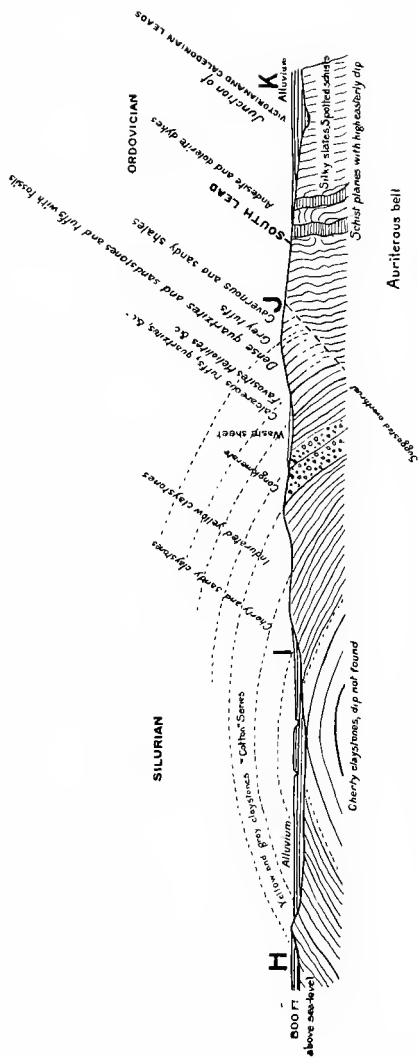


Fig. 7.

Section near Parkes, N.S.W., showing relation of Silurian and Ordovician (?) Strata. (E. C. Andrews.)

and tuffs, jasperoids and cherty claystones, and what appear to be andesitic lava flows. The whole series has been much metamorphosed (Fig. 7.) Silicification of the sediments is characteristic of this series, and numerous gold reefs occur in them. Intrusive andesites appear to have determined the ore entries.

Tweed River District.—A series of highly folded slates, which are possibly of Ordovician age, occurs in this district. These beds, particularly in the neighbourhood of Murwillumbah, contain numerous thin veins of turquoise (hydrous phosphate of alumina); similar veins of turquoise occur in undoubted Ordovician strata at many places in Victoria and in the southern part of New South Wales—for example, near Boddalla; and as there is also a close similarity in lithological character between the Tweed River strata and these Ordovician rocks, the former may be of the same geological age. The wide-spread occurrence of phosphate-bearing slates of Ordovician ages is interesting, and suggests that the secretion of phosphate of lime by marine organisms was more common then than now.

ORDOVICIAN LIFE.

The following fossils have been obtained from the Ordovician strata of New South Wales:—

Protozoa—*Radiolaria*.

Spongida—*Prostospongia*.

Graptolitida—*Dicranograptus furcatus*, *Didymograptus caduceus*, *Dicellograptus extensus*, *Dicellograptus elegans*, *Diplograptus micro-*

natus, *Diplograptus rectangularis*, *Phyllograptus*, *Diplograptus palmeus*, *Diplograptus Carnei*, *Diplograptus Manduramæ*, *Climacograptus bicornis*, *Climacograptus affinis*, *Climacograptus hastata*, *Retiolites caudatus*, *Cryptograptus*, *Glossograptus*.

Brachiopoda—*Obotella*.

Pteropoda—*Hyalithes*.

Trilobita (?)—*Agnostus*.

This, the oldest fauna yet found in New South Wales, would seem to have been pelagic in habit, and to resemble fairly closely that of the Upper Ordovician strata of Victoria. The graptolites are abundant and widespread, but the other genera are local in their occurrence. The known fossiliferous beds are few and far between. The characteristic graptolite fauna of the Lower Ordovician epoch of Victoria, which differs considerably from that listed above, has not yet been found in New South Wales.

SUMMARY OF THE ORDOVICIAN PERIOD.

Of the changes which ushered in the Ordovician Period nothing is known. The only older formation known to exist in the districts in which Ordovician sediments are found is the metamorphic series of the Cooma district, and, as already stated, there is a possibility that these may prove to be metamorphosed Ordovician strata. As the age of this series is in doubt, it throws no light on the question. The evidence obtained from the scattered outcrops of

Ordovician strata is in itself very incomplete. Such evidence as these occurrences yield indicates that the south-eastern and central parts of New South Wales,

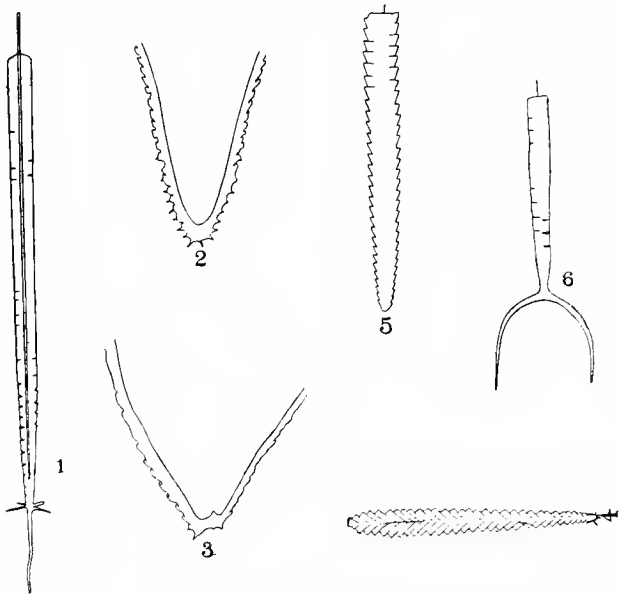


Fig. 8.

Upper Ordovician Graptolites.

1. *Cladograptus hastata* (Hall). 2. *Dicellograptus* c. f. *divaricatus* (Hall).
 3. *Dicellograptus clepsus*. 4. *Diplograptus Carnei* (Hall). 5. *Diplograptus falliens* (Hall). 6. *Cladograptus hircensis* (Hall.)

perhaps even the greater part of the State, was covered by the waters of an epicontinental sea during at least the latter half of the Ordovician Period. The waters of this sea appear to have been too deep for a shallow water fauna to flourish, but its surface waters were populated by a pelagic fauna in which grapto-

lites were the dominant element. The nearest shoreline was too distant for any but the finer sediments to be transported to these regions and deposited. This sea also covered the greater part of Victoria. The Ordovician was a period of considerable volcanic activity, and from submarine volcanoes large andesite lava flows were poured out over the sea bottom, while at the same time immense quantities of volcanic ash were distributed far and wide.

At Tallong, the one place where a junction between the Ordovician sediments and those of the next period has been observed, a well-marked unconformity occurs. The Ordovician strata throughout the State have also, in general, suffered considerably more metamorphism than the known Silurian strata. At the close of the Ordovician period extensive earth-movements took place by which the marine sediments and volcanic rocks, which had accumulated to a thickness of many thousands of feet, were by lateral pressure bent into a series of folds trending approximately north and south. This folding movement must have converted much of the area previously under the sea into dry land. This then became subject to the attack of meteoric forces, by which the folded Ordovician strata were partly denuded; consequently, when the sea readvanced upon these land areas in the next period, the new beds of sediment were deposited unconformably upon the truncated ends of the older strata. This epoch of orogenic earth-movement was one of the most marked which occurs in the geological history of New South Wales.

A marked feature of the Ordovician formation in New South Wales is the association with it of valuable metalliferous deposits, particularly auriferous reefs, in many of the localities where the formation occurs. In some of these localities the adjacent Silurian and Devonian formations appear to be barren of similar ore deposits. It would seem probable, therefore, that the folding of these strata at the end of the period, together with the igneous intrusions which accompany it, were responsible for the formation of at least some of these deposits. From what little is known of them, the igneous intrusions which took place at this time appear to have been intermediate in composition.

CHAPTER VI.

THE SILURIAN PERIOD.

SILURIAN rocks are widely distributed in New South Wales, and outcrop over a larger area, perhaps, than the strata of any other geological age; in addition they probably underlie, to a considerable extent, many of the younger sedimentary formations. Strata of this age, together with the igneous rocks by which they have been intruded, outcrop extensively in the south-eastern quarter of the State, particularly about the head waters of the Murray, Murrumbidgee, and Lachlan Rivers. A second extensive area is that stretching in a north-westerly direction from the western fall of the central tableland past Cobar and Nymagee to the Darling River. Large outcrops also occur in the far West.

Lithologically the Silurian strata consist mainly of slates and limestones of marine origin; littoral deposits such as sandstones, grits and conglomerates are uncommon. Contemporaneous lavas and tuffs are of frequent occurrence, and in some cases attain a considerable thickness. The limestones are usually richly fossiliferous, and in them an abundant and characteristic marine fauna has been preserved. The slates, on the other hand, are seldom fossiliferous, and their geological age has usually been determined by that of the fossiliferous limestones associated with them;

they are rarely true slates and should in most cases be called claystones. The age of considerable areas of these slates has been inferred as Silurian entirely from lithological resemblances; and, as Ordovician graptolites have recently been obtained from quite a number of localities where the strata had previously been assumed to be of Silurian age, it is therefore quite probable that many similar strata in other localities may ultimately be found to be of Ordovician age also, or even to be younger than Silurian.

The Silurian rocks have invariably been strongly folded and tilted, the axes of the folds having a nearly meridional strike, commonly 10° to 20° west of north. This folding has been accompanied by a moderate amount of regional metamorphism, which has had but little effect, in most cases, on the limestone, but which has altered the one-time shales into claystones, talcose slates, &c. The folding has been accompanied by extensive igneous intrusions, mainly granitic, which have caused considerable contact metamorphism, with the resultant conversion of the adjacent Silurian sediments into slates, phyllites, schists, marble, &c.

The Yass-Bowling District.—The great wealth of marine fossils which occurs in the Silurian rocks of this district has long attracted attention, and made them a veritable "happy hunting ground" for the geologist and palæontologist. The strata consist of conglomerates, grits, sandstones, shales, limestones, and tuffs, and are many thousands of feet in thickness.

Mr. A. J. Shearsby subdivides these beds in des-

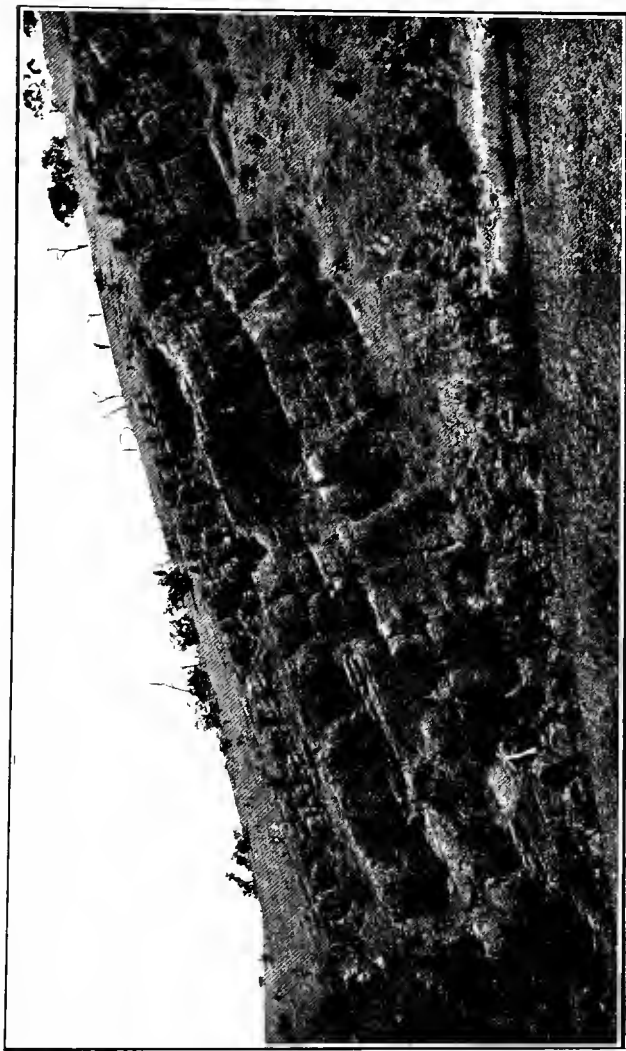


Fig. 9.

Silurian Limestone, Hatton's Corner, near Yass, New South Wales.

ending order as follows, but does not give any thickness for them:—

1. The Hume Beds.
2. The No. 3 Porphyry.
3. The Yass Beds.
4. The No. 2 Porphyry.
5. The Bango Beds.
6. The No. 1 Porphyry.
7. The Jerrawa Shales.

All these beds strike about 20° north of west, and dip at comparatively low angles.

The Jerrawa shales possess no features of special interest, and extend from Gunning to Queanbeyan.

The Bango beds consist mainly of shales, but contain some limestones with fossil crinoids and corals (*Favosites*, *Halysites*, *Tryplasma*, etc.). These beds also outcrop on the Federal Capital site at Canberra. The Yass beds consist mainly of thinly bedded shales, sandstones and grits, with a few thin beds of limestone. Some of the sandstones are false-bedded, while others are ripple-marked and sun-cracked. The limestones and calcareous shales are crowded with well-preserved fossils. The Hume beds consist of similar sedimentary strata well over 2,000 feet in thickness: these outcrop at Hatton's Corner, near Yass, and extend from there to Bowning. Many of these beds are crowded with fossils, among which corals and trilobites are particularly abundant.

Near Bowning the upper portion of the Hume beds

contains thick beds of conglomerates, as will be seen from the following section measured by J. Mitchell:—

SECTION at Bowning. (After Mitchell.)

	feet.
Conglomerates	300
Shales and sandstones	50
Conglomerates	50
Shales and sandstones	150
Shales... ..	250
Shales, sandstones, and conglomerates	185
Shales... ..	1,300
Limestone, impure (with Trilobites)	50
Shales (with Corals and Crinoids)	30
Limestone (with Corals, Brachiopods, &c.)	300
Grits, unknown thickness ... ..	...

The occurrence of considerable thicknesses of conglomerates, grits and sandstones, indicates the proximity of dry land during their deposition; too little is known of the boundaries of this formation, however, for any definite opinion to be formed as to the extent and position of these land areas.

The three porphyry beds mentioned in Shearsby's section appear for the most part to be contemporaneous lava flows and tuffs, although some part of them is possibly intrusive. The lavas are acidic in composition and are devitrified rhyolites: the tuffs have a similar composition. The whole series of volcanic rocks interstratified with the Silurian sediments has a considerable thickness, at least several thousands of feet: columnar structure characterises some of these rhyolite lavas.

At Boambola, a few miles to the south of Yass, the following succession of strata (in descending order)

has been measured by Messrs. L. F. Harper and W. S. Dun:—

	Thickness in feet.
Grits and shales	200
Limestone (with <i>Syringopora</i> and <i>Heliolites</i>) ...	30
Shales	100
Impure limestone (with <i>Favosites</i>)	25
Shales, sandstones, and quartzites	500
Bouldery limestones	10
Grits, sandstones, and quartzites, with nodules of limestone	100
Limestone	20
Grits and shales, with limestone nodules	150
Limestones, (with <i>Tryplasma</i> and <i>Pentamerus</i>) ...	100
Grits	100
Shales and rubbly limestones	125
Grits, shales, and quartzites, with ripple-marks and worm-tracks	1,200
Glenbower beds (shales, with bands of grit) ...	840
Total	3,500 feet

The Glenbower beds contain abundant Silurian fossils, including Corals (*Heliolites*, *Favosites*, *Cyathophyllum*, *Tryplasma*, *Heliophyllum*) Brachiopods (*Pentamerus*, *Spirifera*, *Atrypa*), Cephalopoda (*Orthoceras*, *Actinoceras*), and Trilobites (*Phacops* and *Encrinurus*). This is a similar fauna to that which occurs in the Hume beds. This series of strata, which is almost certainly the equivalent of the Hume beds of Yass, was undoubtedly deposited along a shore-line, though at times the stoppage of terrigenous sediments allowed of the formation of the limestone beds; the conditions were probably those of intermittent changes in the level of the land, which brought about an alternating advance and retreat of the shore-line.

Jenolan District.—This lies in the heart of the Blue Mountains, and the Silurian strata here are characterised particularly by the occurrence of Radiolarian deposits. The lowest beds exposed consist of red and green claystones and talcose-slates (Fig. 10), some of the former containing numerous Radiolarian casts. Following these, there is a rhyolite lava-flow, 300 feet in thickness; then come more claystones, about 300 feet in thickness; immediately above these is a massive bed of limestone, about 500 feet in thickness, which is succeeded in turn by beds of claystones and Radiolarian cherts, upwards of 1,000 feet in thickness. The whole series has been strongly folded, and the beds now have a steep angle of dip. In the cherts above the limestone the Radiolaria, which are preserved in the form of chalcedonic casts, occur in enormous numbers. The limestone bed has been traced for many miles in the direction of its strike (N. 10° W.), and consists mainly of the remains of Corals (*Favosites*, *Heliolites*, &c.), Brachiopods (*Pentamerus*), Crinoids, and Hydrozoa (*Stromatopora*). The series, as a whole, has been extensively intruded by granite and quartz-porphry, and at the junction of these igneous rocks with the sedimentary rocks interesting contact breccias occur, consisting of subangular fragments of claystone and limestone embedded in the porphyry. At Wombeyan, some 30 miles to the south, a thick series of massive limestones and tuffs has been almost entirely surrounded by plutonic intrusions, and the limestone has been metamorphosed into a coarse white crystalline marble.

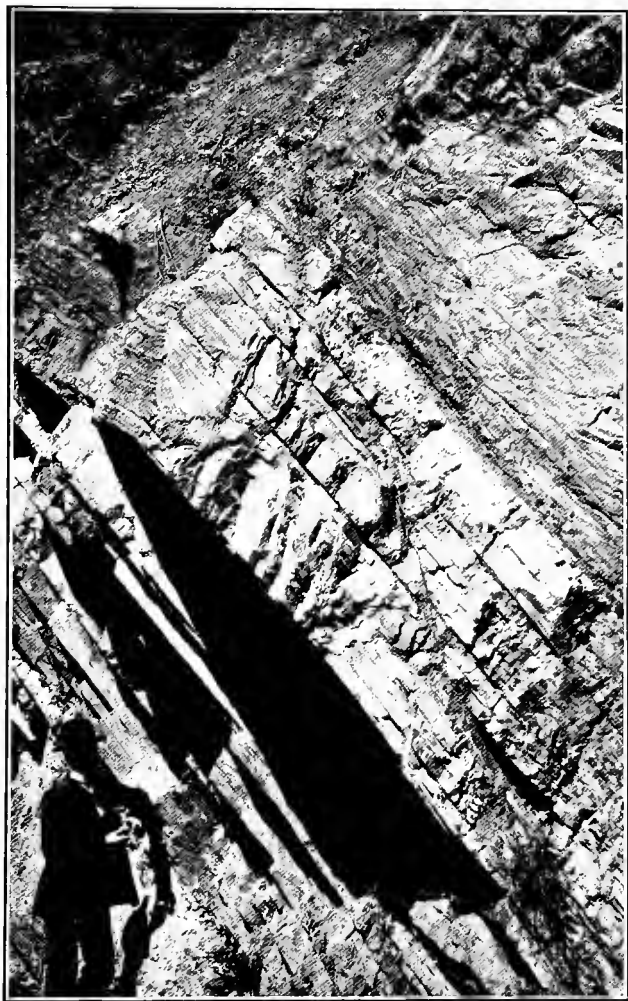


Fig. 10.

Silurian Claystones, Jenolan Caves, New South Wales.

In the limestones at Jenolan, Wombeyan, and Yarrangobilly occurs that wonderful series of caverns whose majestic proportions and infinite variety of form have made them world-famous. The caves occur where stream channels cross the limestone belts, and have resulted from the action of water charged with carbon-dioxide dissolving away the limestone. River gravels, containing water-worn boulders up to 12 inches or more in diameter, are frequently met with in these caves, even in those high up on the hillsides, giving evidence of the fact that the river at one time flowed through them, as, in fact, it still does through those at the lowest levels. Percolating rainwater has subsequently ornamented the walls of the caves with the beautiful stalactitic and stalagmitic formations, whose bewildering beauty is a never-ending source of wonder and delight to visitors.

The Bathurst District.—The Silurian strata here consist of alternating beds of claystone and limestone. In the neighbourhood of the town of Bathurst they have been extensively intruded by granite, and have suffered considerable contact metamorphism therefrom. The limestones have been altered into crystalline marbles, in which secondary minerals—such as Wollastonite, Tremolite, Garnet, &c.—are common, whilst the claystones have been altered into mica-schists, talc-schists, actinolite-schists, chiastolite-slates, &c. Some of the limestones—those at Limekilns, for example—contain numerous large cephalopods (*Orthoceras*, &c.); corals are also common, and of these, *Phillipsastrea* is perhaps the most characteristic.

To the north of Bathurst, on the Hillend and Hargraves gold-fields, thick beds of tuff and several rhyolite lava-flows are interstratified with the Silurian sediments; these flows range up to 400 feet in thickness. On the Hargraves gold-field the folding of the sedimentary rocks has been accompanied by the formation of saddle-shaped cavities (Fig. 11) between certain adjacent beds along the axes of some of the

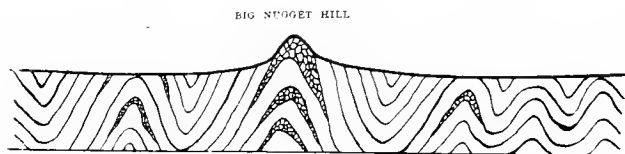


Fig. 11.

Sketch-section across Big Nugget Hill, near Hargraves, New South Wales, showing saddle-reefs in folded Silurian Strata. (After Watt.)

anticlinal folds. These cavities have been filled subsequently with auriferous quartz, and saddle-reefs analogous to those occurring on the Bendigo gold-field in Victoria have thus been formed. Six distinct lines of these saddle-reefs are known to occur, but comparatively little mining work has been done on them.

The Orange-Molong District.—In this district, which is on the western fall of the Central Tableland of New South Wales, the Silurian formation consists mainly of slates and limestones. The limestone beds here are very numerous and individually attain a thickness of upwards of 400 feet; but they seldom

SUCCESSION OF STRATA
along
OAKY CREEK
in

PORTIONS No 249 to 136.

Thickness.

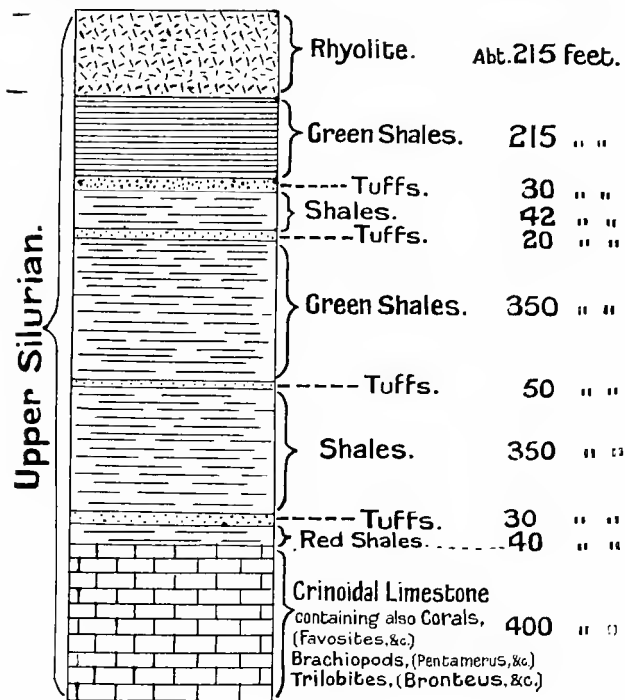


Fig. 12.

Section showing succession and thickness of Silurian Strata, Oaky Creek,
near Orange, New South Wales.

maintain this thickness for any considerable distance, thinning out rapidly when followed in the direction of their strike. Corals, crinoids, and brachiopoda have supplied the bulk of the carbonate of lime for their formation. At Borenore, Molong, and other localities excellent marbles of various colours are obtained from these beds. Towards the top of the series rhyolite lavas and tuffs occur to a considerable extent. Fig. 12 represents a section of the topmost beds as they occur along Oakey Creek, County of Ashburnham, some 12 miles from Orange.

Halysites is the most abundant of the fossil corals found here, and is represented by six different species. *Arachnophyllum*, a large and handsome coral, is also plentiful; it has not yet been found elsewhere in Australia. *Mictocystis* is another interesting but rare genus. The other genera found here include *Favosites*, *Heliolites*, *Mucophyllum*, *Zaphrentis*, and *Cyathophyllum*. All have been more or less silicified and are wonderfully well preserved. The trilobites are not numerous.

The thickness of the silurian strata in this district is unknown, but is probably not less than 5,000 feet. The great development of limestones and the absence of littoral deposits show that sedimentation was taking place in this region in a comparatively shallow sea, but at a considerable distance from dry land. The tuffs and lava-flows indicate that submarine vulcanism became a pronounced feature towards the close of the period.

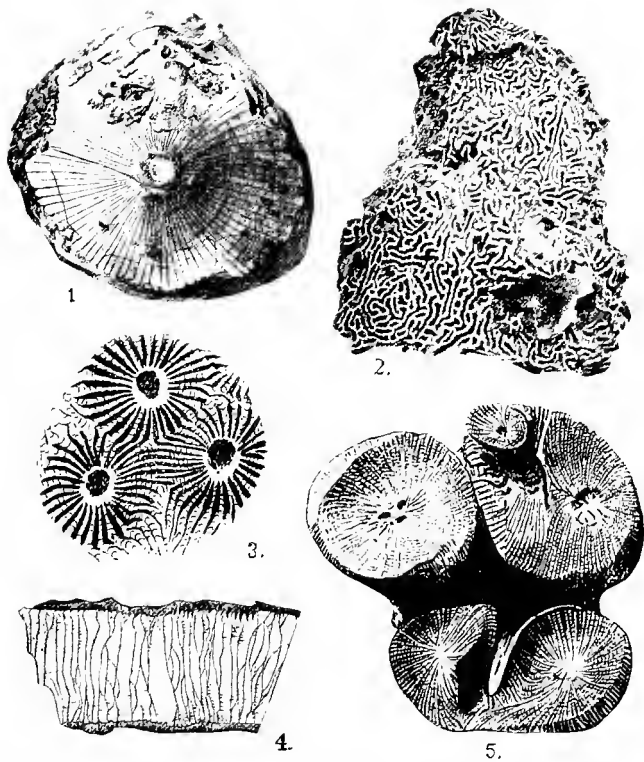


Fig. 13.

Characteristic Silurian Corals.

1. *Macophyllum crateroides* (Eth. filis). 2. *Hulsites peristephesicus* (Eth. filis).
 3. *Phillipsastrea Currani* (Eth. filis); section showing the confluent septa.
 4. *Tryplasma columnaris* (Eth. filis); section of a corallite showing the spinose septa and the tabulæ. 5. *Heliophyllum Yussense* (Eth. filis).

In the vicinity of the towns of Parkes and Forbes the silurian strata consist of sandstones, quartzites, tuffs, conglomerates, limestones, and laminated claystones folded into gentle anticlines and synclines. They appear to have been faulted against the Ordovician (?) strata, and have been traced from Forbes in a northerly direction for a distance of about 20 miles. In the northern part of the district the marine sediments appear to have been replaced in part by andesite flows and tuffs. Typical silurian fossils occur in the sedimentary beds, including corals (*Tryplasma*, *Halysites*, *Syringopora*, *Cyathophyllum*, *Favosites*, *Heliolites*); Brachiopods (*Pentamerus*, *Leptaena*, *Orthotetes*); Trilobites (*Phacops*, *Hausmannia*). The thickness of these strata is at least 5,000 feet. No metalliferous deposits are known to occur in these beds, being apparently confined to the older Ordovician strata.

The Wellington District.—A thick series of limestones and claystones similar to those of the Orange District occurs near the town of Wellington. The silicious sponge, *Astylospongia*, is very abundant in these beds near the Wellington Caves.

The Western Areas.—An extensive development of silurian strata stretches in a north-west direction from the Orange-Molong district nearly to the Darling River. This area embraces the important mining fields of Cobar, Nymagee, Mount Drysdale, Mount Hope, and Mount Boppy. The greater part of this region is relatively flat and covered with surface soil, consequently few good outcrops occur. These

Silurian strata, so far as they have been investigated, appear to be of great thickness and consist mainly of claystones; but interbedded with these there are limestones, sandstones, conglomerates and radiolarian cherts. The limestones in some localities, as for example at Rookery Station, 22 miles south-west of Cobar, are fossiliferous and have yielded among others, *Favosites*, *Alveolites*, *Tryplasma*, *Heliolites*, *Stromatopora*, *Orthoceras*, *Spirifer*, *Atrypa*, *Pentamerus* and *Rhynchonella*. The sandstones are for the most part thinly-bedded and frequently exhibit current-bedding. The conglomerates are widely distributed, and in places have suffered considerable metamorphism, the pebbles being drawn out into double-ended cigar-like forms, or into discoidal forms; in some cases the pebbles have been sheared and faulted. These conglomerates mark the position of an old shore-line lying to the east of Cobar, and extending for a distance of at least 60 miles.

The Radiolarian cherts outcrop at several localities, but the most typical occurrences are those near Canbelego, where the rock is crowded with Radiolarian casts. In this district also occurs a series of contemporaneous rhyolite lava flows and tuffs, of considerable thickness, which extend with a discontinuous outcrop for a distance of nearly 100 miles. This occurrence of rhyolite lavas and radiolarian cherts in Silurian strata is similar to that in the Jenolan District already described. The ore deposits, auriferous and cupriferous for the most part, are in many cases, as at Cobar for example, of

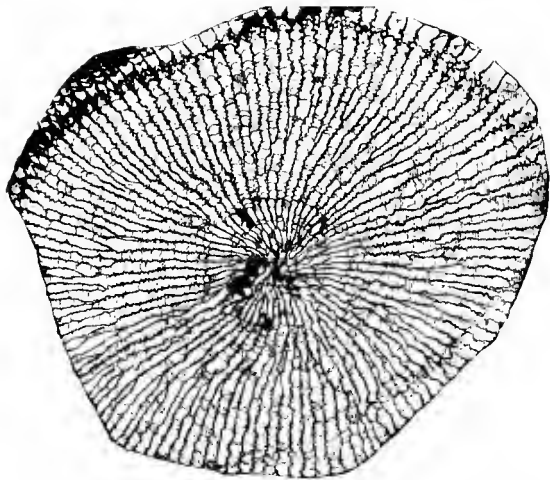


Fig. 14A.

Heliophyllum.—A characteristic Silurian Coral.
Cross section of a large coralite.

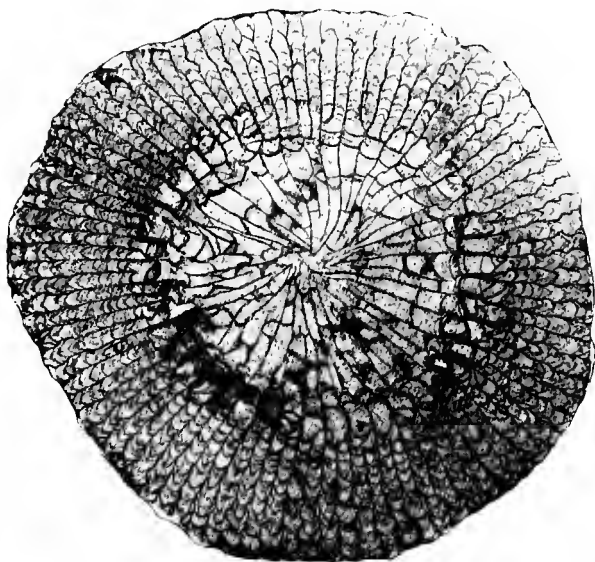


Fig. 14B.

A large Silurian Coral—*Cyathophyllum Shearsbyi*.
Section across a simple corallum.

large size, and have been produced by the metasomatic replacement of the country rock along lines of overthrust faulting.

Similar areas of Silurian strata (so-called) exist beyond the Darling River, varying individually from a few square miles to hundreds of square miles in area. The manner in which the outcrops of these strata project (like islands) above the surface of the Mesozoic and Tertiary sediments suggests that similar strata underlie these later sediments throughout the greater part of this western district.

ECONOMIC ASPECTS OF THE SILURIAN PERIOD.

Many of the Silurian limestones present a very handsome appearance when polished, and display considerable variety in colour and pattern. Some of these have already been extensively used for ornamental purposes in the buildings of the metropolis; the available supply of this material is practically inexhaustible. Large quantities of limestone are also quarried annually for lime-burning, cement-making, and for use as a flux in smelting operations. Of the slates no deposits have yet been found with a fissile structure sufficiently perfect to make them available for use as roofing slates, or for other building purposes. It is the metalliferous wealth, however, which gives the Silurian formation its greatest economic value. Many important gold and copper mining fields are situated in areas where the enclosing strata are believed to be of Silurian age. The mineral deposits themselves are, of course, of later geological ages than the strata with which they are

associated, as they could have been formed only after the latter had been folded and fractured. Many of these ore-deposits are true "fissure veins," but some of the larger ones, particularly those containing copper, are metasomatic replacements of the slates and claystones along "shear zones." These latter deposits usually have no definite walls, and the productive ore bodies are more or less lens-shaped, and are arranged along lines of over-thrust faulting.

SILURIAN LIFE.

The great wealth of fossils found in the Silurian strata of New South Wales shows that very favourable conditions for the development of marine invertebrate life must have existed in the Silurian seas. The great variety of classes, orders, and genera which constitute this marine fauna is in marked contrast to that of the preceding Ordovician period, in the fauna of which Graptolites so largely predominated.

PROTOZOA.—Radiolaria occurred in enormous numbers in the Silurian seas, and where conditions were favourable for their tests to accumulate without too much admixture of other sediment, as at Jenolan and in the Cobar District, characteristic radiolarian deposits were formed.

SPONGIDA.—Small sponges occur, but representatives of this class do not appear to have been generally abundant.

HYDROZOA.—Graptolites, which occupied such a predominating position in Ordovician times, are not found. This group apparently became extinct in Australia at the close of the Ordovician. *Stromato-*

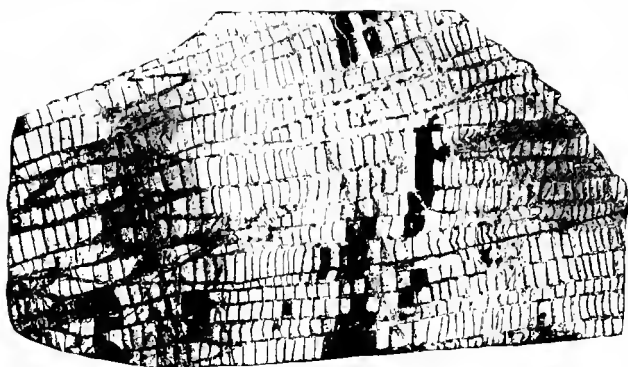


Fig. 14C.

A common Silurian and Devonian Coral—*Favosites*.

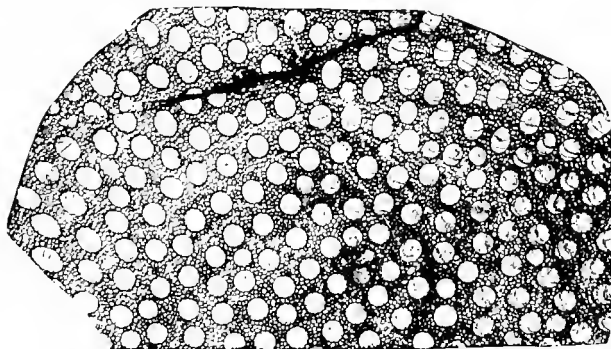


Fig. 14D.

Heliolites.—A common Silurian and Devonian Coral.

pora, a genus allied to the hydrocorallines, becomes very abundant, and contributed largely to the formation of the limestones of this period.

ACTINOZOA.—These appear suddenly in great numbers. All the important Palæozoic groups, viz., the Tetracoralla, the Tabulata, and the Octocoralla, are represented by numerous families and genera; many of these were reef-building types. Such well-known genera as *Favosites* and *Heliolites* occur abundantly and are very widely distributed. Certain genera such as *Halysites*, *Mucophyllum*, *Rhizophyllum*, *Arachnophyllum*, *Phillipsastrea*, are, so far as is known, limited in their range in New South Wales to the Silurian Period. Some had a very wide geographical range; others, again, appear to have been confined to limited areas. The genus *Arachnophyllum*, for example, occurs abundantly in the Orange-Molong district, but is unknown in the Yass-Bowning district. Such restrictions are due, most probably, to differences of environment rather than to land barriers preventing migration. Individual coralla among the compound corals attained large dimensions.

ECHINODERMATA.—Crinoids occurred in immense numbers; certain parts of the sea bottom, at times, must have been covered with veritable "forests" of these organisms, as large thicknesses of limestone in various localities consist very largely of "crinoid stems." Owing to the fragmental state in which they have been preserved, little is known of the genera to which they belonged. Starfish and echinoids are rare.

POLYZOA.—Generally speaking, these are not common. Considerable numbers, however, occur in some of the Yass beds, particularly in those in which the Trilobites are found. The most common genus is *Fenestella*.

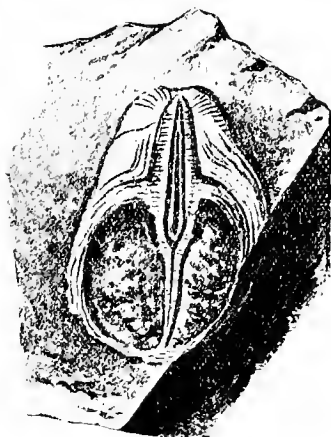


Fig. 16.

Weathered specimen of *Pentamerus* in limestone.

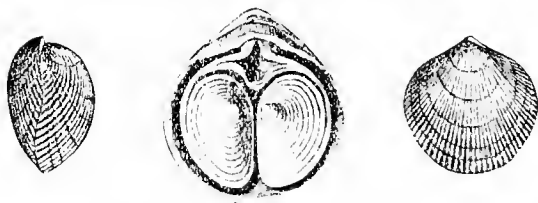


Fig. 17.

A characteristic Silurian Brachiopod.—*Atrypa reticularis*.

BRACHIOPODS.—These stand second in importance to the corals, and flourished abundantly in the Silurian seas. The cosmopolitan species *Pentamerus*

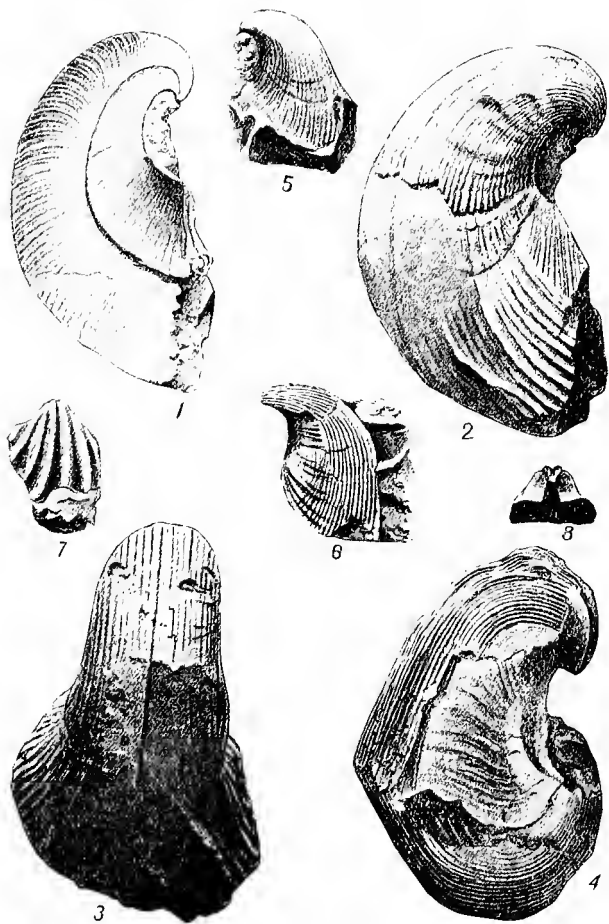


Fig. 15.

Characteristic Silurian Brachiopods.

1-6. *Pentamerus (Concridium) Knightii*. 7-8. *Pentamerus costatus*.

Knighiti (Fig. 15) and *Atrypa reticularis* are the most abundant; the former, in particular, contributed very largely to the formation of some of the limestone beds.

MOLLUSCA.—These occupy a very secondary position as compared with the Brachiopods, but were abundant in some localities. Pelecyopods are not common. Gasteropods are represented by such genera as *Loxonema*, *Murchisonia*, *Oriostoma*, *Cyclonema*. The Cephalopods all belonged to the straight-shelled nautiloid types, such as *Orthoceras*, which individually attained a considerable size, and in certain localities occurs in considerable numbers.

TRILOBITA.—These flourished in great numbers in the Silurian seas covering what is now the Yass-Bowning district. The muddy, shallow water of the shore-line seems to have been their favourite habitat. Elsewhere they appear to have been uncommon. Over

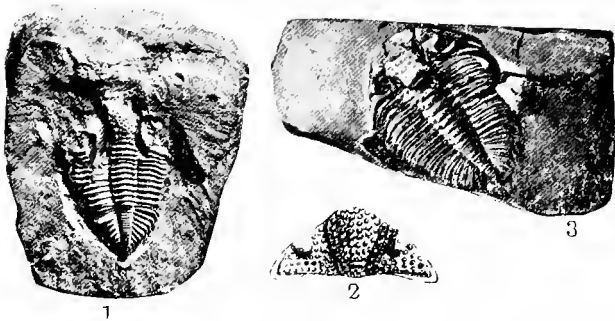


Fig. 18.

Silurian Trilobites.

1. *Eucrinurus Mitchellii*.
2. Cephalon of *Eucrinurus Barrandi* (De Kon.).
3. *Phacops*.

fifteen genera and a large number of species have already been described. *Encrinurus* (Fig. 18), *Phacops* (Fig. 18), *Hausmannia*, and *Brontcus* are the most common genera.

Plants.—Impressions of Algae (sea-weeds) are found in some of the marine shales, but no trace of any terrestrial vegetation has yet come to light. The high state of development of the land flora of the next period (Devonian), and the marked differentiation exhibited by the different groups represented, makes it highly probable that their progenitors already existed in Silurian times.

LIST OF THE MORE IMPORTANT SILURIAN FOSSILS.

Protozoa.—*Radiolaria* were abundant.

Spongida.—*Astylospongia*, *Receptaculites*.

Hydrozoa.—*Stromatopora*.*

Actinozoa—(a) TETRACORALLA, *Petraia*, *Zaphrentis*, *Mucophyllum*, *Cyathophyllum*,* *Tryplasma*,* *Phillipsastrea*, *Heliophyllum*, *Rhizophyllum*, *Arachnophyllum*, *Spongophyllum*.*

(b) TABULATA, *Favosites*,* *Pachypora*, *Chætetes*, *Halysites*,* *Syringopora*,* *Striatopora*. (c) OCTOCORALLA, *Heliolites*.*

Crinoidea—*Pisocrinus*.

Echinoidea—*Palæchinus*.

Asteroida—*Palæaster*.

Vermes—Jaws of errant Annelids occur.

Polyzoa—*Fenestella*,* *Glaucanome*, *Thamniscus*.

* These genera are the most abundant.

Brachiopoda—*Lingula*, *Pentamerus* (*Conchidium*),* *Atrypa*,* *Rhynchonella*,* *Anoplothecca*, *Camarotæchia*, *Meristina*, *Cyrtina*, *Strophomena*, *Orthotetes*, *Spirifer*, *Orthis*.

Pelecypoda—*Conocardium*, *Anodontopsis*.

Gasteropoda—*Euomphalus*, *Trochus*, *Cyclonema*, *Oriostoma*, *Bellerophon*, *Loxonema*,* *Murchisonia*, *Omphalotrochus*, *Mourlonia*.

Pteropoda—*Tentaculites*, *Hyalithes*.

Cephalopoda—*Orthoceras*,* *Actinoceras*, *Gomphoceras*.

Trilobita—*Acidaspis*, *Cromus*, *Encrinurus*,* *Calymene*,* *Harpes*, *Bronteus*,* *Cheirurus*, *Prætus*, *Phacops*,* *Cyphaspis*, *Lichas*, *Staurocephalus*, *Illanus*, *Hausmannia*.*

Summary of the Silurian Period.—The earth movements which closed the Ordovician Period were followed in New South Wales by long-continued sedimentation. The nature and distribution of the sediments then deposited, so far as our knowledge goes, indicates that the greater part of New South Wales was covered by the sea. The occurrence of littoral deposits (conglomerates, grit, sandstones, &c.) in the Yass-Bowling, the Parkes-Forbes districts, and in the Cobar district points to the existence of neighbouring land in these areas. This land probably lay to the south and west, but our present knowledge of the distribution of these littoral deposits is too incomplete to attempt a reconstruction of the boundaries of Silurian land and sea. Elsewhere, littoral deposits appear to be absent, while the general occurrence of alternating

claystones and limestones indicates tranquil deposition in a comparatively shallow open sea. The abundance of reef-building corals shows the water of this sea to have been warm, as these organisms, judging by their present-day representatives, cannot live in water with a lower temperature than 68° Fahrenheit. The great thickness of strata deposited (perhaps 10,000 feet or more) could only have been possible if the sea bottom had been slowly subsiding, while the alternation of claystones and limestones indicates that the subsidence was more or less intermittent. This tranquil and long-continued sedimentation was at times interrupted, particularly towards the close of the period, by submarine volcanic eruptions, which covered the surrounding sea-floor with large deposits of volcanic ash and lava.

At the close of the Silurian Period, a pronounced deformative movement affected the earth's crust, which folded and elevated the Silurian strata to such an extent that considerable areas were probably uplifted above sea-level. Our incomplete knowledge of the nature and distribution of the succeeding Devonian sediments makes it impossible to form any definite opinion as to the extent of this movement, or of the position and actual extent of the land areas produced by it. This will be discussed more fully in the next chapter.

This deformative movement which closed the Silurian Period appears to have been accompanied in some districts by important ore-making conditions. In the Cobar district, for example, important and

widely-distributed ore-deposits occur in Silurian strata. In the Upper Devonian rocks of the same district, however, no such ore-deposits are found; it would seem probable, therefore, that these strata were not subjected to the orogenic movement which produced the ore-making conditions.

CHAPTER VII.

THE DEVONIAN PERIOD.

THE distribution of the Devonian Formation corresponds, in a general way, with that of the Silurian, but the superficial area at present occupied by it is very much smaller. The outcrops, particularly those of the Upper Devonian Series, are, as a rule, individually small in area, and are often widely separated from one another. These isolated outcrops appear to be the remnant of what was, at one time, a very extensive formation. Extensive areas, however, do occur, such as that of the Mount Lambie-Capertee district, on the western edge of the Blue Mountains.

The New South Wales Devonian strata have been provisionally divided into two series, as follows:—

The Upper Devonian Series (Lambian Series)—
Mt. Lambie, Capertee, Molong, Braidwood, and
Yalwal Beds.

The Lower Devonian Series. (Murrumbidgean
Series)—The Tamworth Beds; the Murrum-
bidgee Beds.

THE LOWER DEVONIAN OR MURRUMBIDGEAN SERIES.

This series has sometimes been referred to the Middle Devonian Epoch, following the classification used in Victoria. The strata are all marine in origin,



Fig. 19.

Lower Devonian (Murrumbidgean) Limestones and Shales, folded into an anticline, Taemas,
Murrumbidgee River, New South Wales.

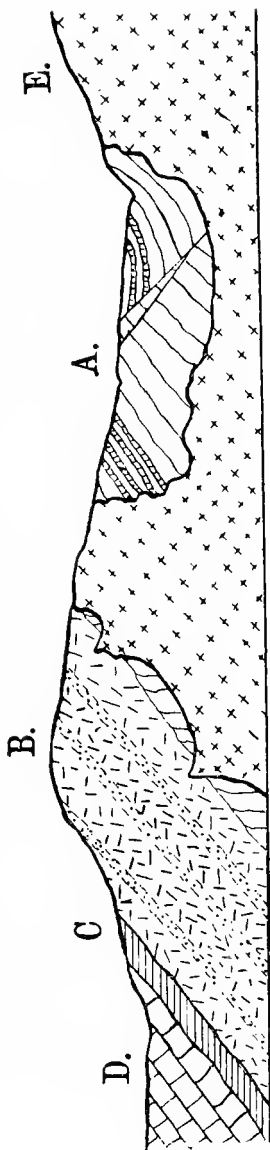


Fig. 20.

Section of Silurian and Lower Devonian Strata at Cavan, Murrumbidgee River, near Yass. (After Harper.)

A = Silurian limestones and claystones. B = Volcanic series (Rhyolite lavas and tuffs), Lower Devonian. C = Tuffs, Lower Devonian.
 D = Basal limestones, Lower Devonian. E = Intrusive quartz-porphyrity.

and have yielded an abundant fossil fauna, in which corals are the most conspicuous element. Lithologically the strata are not unlike those of the Silurian formation, but important differences occur in the contained fossils. Littoral deposits appear to be absent.

I. *The Murrumbidgee Beds.*—These occur along the course of the Murrumbidgee River, immediately above its junction with the Goodradigbee River, and extend for a considerable distance to the south along the watershed of the latter. The junction of these beds with the adjoining Silurian strata is obscure, the two being separated by extensive quartz-porphry intrusions (Fig. 20); but an unconformity is believed to exist. The Murrumbidgee Beds, as measured by Mr L. F. Harper, have an average total thickness of about 14,000 feet, and consist of the following rocks:—

	Maximum Thickness feet.
Dark-blue shales (with interbedded tuffs) . .	7,000
Limestones (with interbedded shales and tuffs) . .	5,000
Rhyolite lavas and tuffs (volcanic stage) . .	5,000

(a) *The Volcanic Stage.*—This occurs at the base of the series, and consists of rhyolite lava flows and tuffs. These may be correlated with the Snowy River porphyries of Victoria, which occupy a similar stratigraphical position in that State, and which they much resemble in their lithological characters. The thickness of the volcanic beds is variable, but they attain a maximum thickness of 5,000 feet at Cavan. They are believed to have been derived from several distinct centres of eruption.

(b) *The Limestone Stage.*—This has a maximum thickness of about 5,000 feet, and, in addition to the limestone, includes numerous thin beds of shale, quartzite, and tuff. The limestones are largely coralline in origin, but some of the beds near the base of the series are built up mainly of brachiopod shells (*Spirifer*, *Chonetes*, &c.). The following detailed section of the lower beds of this stage, and of the volcanic beds, as they occur at Cavan, has been measured by Mr. Harper:—

Limestone Stage.

	Thickness. feet.
Second limestone series	(Not measured.)
Siliceous shales and quartzites (with lenticular limestone beds)	1,800
Basal limestone series	2,250
Tuffs (with bands of shale and limestone)	150

Volcanic Stage.

Rhyolite tuff	100
Rhyolite lavas and tuffs	5,000

The great thickness of limestone in this series is only equalled in Eastern Australia by that of the Burdekin Beds of Queensland, which are also of Devonian age.

(c) *The Tuffaceous Shale Stage.*—The dark-blue shales which follow the limestone stage not only include definite beds of tuff, but are, more or less, tuffaceous throughout. Several small rhyolite flows occur near the top of the series.

It has been estimated that at least 8,000 feet of the Murrumbidgee Beds are composed wholly or partly of volcanic material. The limestone series and the overlying blue shales may be taken as the equivalents of the Middle Devonian formations of Victoria (Buchan and Bindi Beds). Similar limestone beds to those on the Murrumbidgee have been observed as far south as Lobb's Hole, and occur on the Snowy River, just across the Victorian border. The following is a comparison of the Devonian rocks of Western Victoria and Southern New South Wales.—

	<i>Victoria.</i>	<i>New South Wales (Southern).</i>
Upper Devonian	Mount Tambo and Iguana Creek Beds.	Genoa Creek, Pambula, and Braidwood Beds.
Middle Devonian	Buchan and Bindi Beds.	(Murrumbidgee Beds— Tuffaceous shale stage Murrumbidgee Beds— Limestone stage.
Lower Devonian	Snowy River Por- phyries.	Murrumbidgee Beds— Volcanic stage.

There seems to be no reason for separating the volcanic stage of the Murrumbidgee Beds from the overlying marine beds; the two appear to be conformable, and the vulcanicity continued, to a greater or less degree throughout the deposition of the marine strata.

II. *The Tamworth Beds.*—The Lower Devonian formation in the Tamworth district is described by Messrs. David and Pittman as having a thickness of upwards of 9,000 feet, and consisting of coralline limestones, radiolarian limestones, claystones, tuffs,



Fig. 21A.
A Silurian Hydrozoan.—*Stromatopora*.

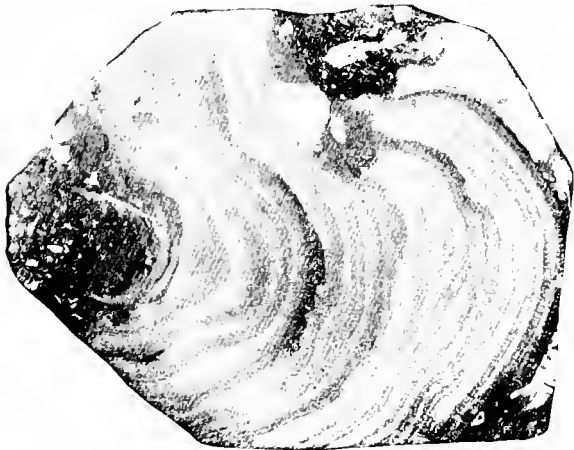


Fig. 21B.
A Silurian Hydrozoan.—*Stromatopora*.

and radiolarian cherts. The following section has been measured by them.

	Thickness, feet.
Claystones and tuffs with <i>Lepidodendron</i>	1,450
Cherty shales with beds of tuff and lenticular beds of radiolarian lime- stone	1,430
Claystones, tuffs, radiolarian cherts, and radiolarian limestones	1,960
Tuffs with <i>Lepidodendron australe</i> ..	7
Claystones with <i>Lepidodendron australe</i>	50
Radiolarian cherty shales with inter- bedded radiolarian limestones and tuffs	4,150
Coralline limestones	140-1,000
Claystones	Unknown thickness.

It will be seen that the basal volcanic series of the Murrumbidgee area is apparently absent here; nevertheless long-continued volcanic activity is evidenced in the abundance of volcanic ash which occurs throughout the series. This volcanic material varies from acidic to basic in composition, and some of the tuff beds individually attain a thickness of 100 feet. The limestone beds of the two areas are not very similar in their fossil contents, as will be seen from the comparison of the fossils given later. The beds which succeed the limestones possess two features of special interest; (1) the great abundance of Radiolaria; (2) the occurrence of *Lepidodendron australe*. In the black cherts radiolarian casts occur to the extent of 1,000,000 to the cubic inch, and the rock contains

over 90 per cent. of silica. The claystones also contain casts of these organisms, but in a lesser degree; these beds are fine-grained, often minutely laminated, and occasionally ripple-marked. The radiolarian limestones occur as thin lenticular beds, varying from a few inches up to 2 feet in thickness, and are irregularly interstratified with other radiolarian rocks. In composition they consist largely of carbonate of lime, but contain about 18 per cent. of silica, the latter due mainly to the presence of the radiolaria; as no other fossils have yet been found in them, the source of the carbonate of lime is unknown. It will be seen that all the Tamworth Devonian rocks are remarkably fine-grained in texture; this fact, together with the abundance of radiolaria, might be taken to indicate that they were deposited in deep water. The presence however, of plant remains (*Lepidodendron*) on at least three distinct horizons, the occurrence of limestone beds, and of ripple-marks on some of the shales, are opposed to this view. It seems probable, therefore, that this series of strata was deposited in a sea, not necessarily very deep, but sufficiently far removed from land to be beyond the reach of any but the very finest sediments.

The Devonian strata of the western part of New England have been subdivided by W. N. Benson as follows:—

	Apparent Thickness.
The Barraba Mudstones	13,000 feet
The Baldwin Agglomerates .. up to	1,800 ..
The Tamworth Series	10,000 ..
The Woolomin Series	?



Fig. 21C.

Syringopora.—A characteristic Silurian and Devonian Coral.

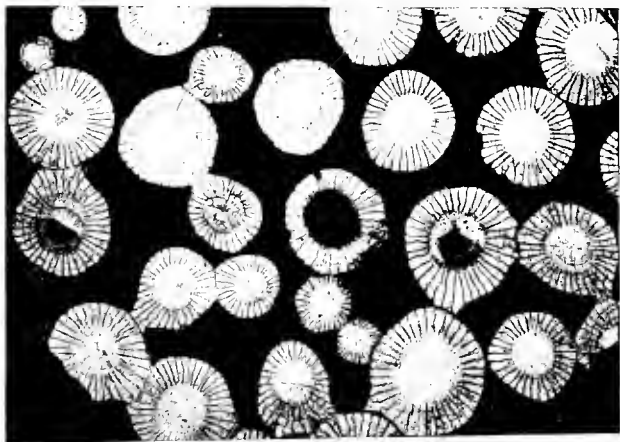


Fig. 21D.

Diphyphyllum gemmiforme.—A characteristic Lower Devonian Coral.

The Woolomin Series consists of red jaspers with radiolaria, claystones, tuffs, and spilite lavas. The Tamworth Series is that already described above; spilite lava flows are numerous in this series, particularly near Nundle. The Baldwin Agglomerates are coarse fragmental rocks containing rounded pebbles of the older rocks set in a tuffaceous matrix. Occasional small rapidly-chilled flows of spillite are interstratified with them, and more rarely very fine-grained felspathic cherts containing radiolaria. These beds extend from Tamworth to Bingara, a distance of 100 miles. The Barraba mudstones contain frequent radiolarian bands, as well as beds of andesitic tuff. The fossil lycopod, *Lepidodendron australe*, is abundant. These beds have a very wide distribution in this region, covering an area of more than 1000 square miles.

The spilite lavas mentioned above are dense fine-grained basic volcanic rocks very much like basalts, from which they differ in containing a rather high percentage of alumina and of soda (4.5 per cent.), while the felspar consists largely of the albite or oligoclase varieties instead of the usual labradorite of the ordinary basalts.

A very conspicuous feature in this district is a dyke-like belt of serpentine, from a quarter to half a mile in width, extending in a south-south-east direction from Warialda for a distance of above 180 miles. This rock, which is an altered peridotite, intrudes the Devonian strata; a zone of red and dark grey

jasperoid cherts, several hundreds of feet in width, occurs along the junction and contains abundant radiolarian casts. This intrusion has materially influenced the metalliferous character of the adjoining sedimen-

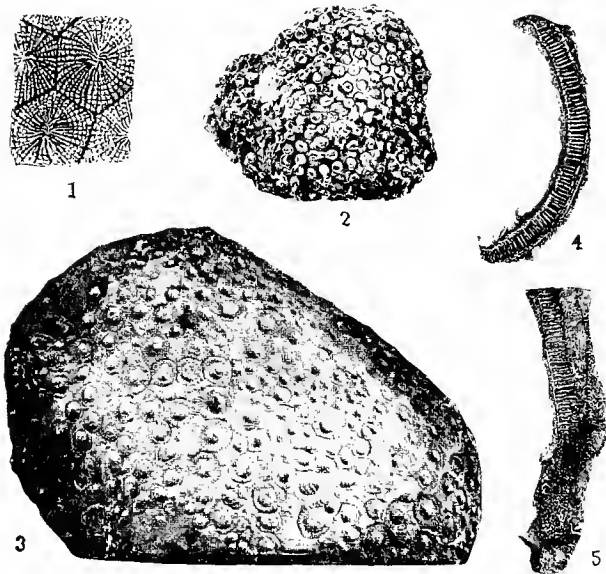


Fig. 22.

Lower Devonian Corals and (?) Sponges.

1. *Cyathophyllum Mitchellii*. 2. *Syringopora spelcaua*. 3. *Diphyphyllum geminiforme*.
4 and 5. *Receptaculites australis*.

tary rocks, with the result that numerous auriferous reefs occur in them in close proximity to it as at Bingara, Wood's Reef, Ironbark, Bowling Alley Point, and Nundle.

LOWER DEVONIAN LIFE.

The following are lists of the fossils collected from the two important districts where rocks of this age are developed:—

Murrumbidgee District.

Plantæ— ———
 Spongiada—*Rceptaculites Australis.*
 Hydrozoa—*Stromatopora.*
 Actinozoa—

Diphyphyllum gemmiforme.
Cyathophyllum Mitchelli.
Syringopora spelcana.
Favosites.
Cystiphyllum.
Zaphrentis.
Campophyllum.

Tamworth District.

Lepidodendron australe.
 ———
Stromatopora.
Diphyphyllum Porteri.
 „ *robustum.*
Syringopora auloporoides.
 „ *Porteri.*
Favosites gothlandica.
 „ *basaltica.*
Sanidophyllum Davidis.
Spongophyllum giganteum.
Actinocystis.
Alveolites alveolaris.
Litophyllum Konincki.
Heliolites porosa.

Brachiopoda—

Spirifer Yassense.
Chonetes Culleni.
Rhynchonella Wilsoni
Atrypa desquamata.

Atrypa reticularis.

Gasteropoda—	————
<i>Pleurotomaria</i> .	
<i>Murchisonia</i> .	
<i>Bellerophon</i> .	
<i>Dentalium tenuissimum</i> .	
Cephalopoda— <i>Orthoceras</i> .	————
Pisces— <i>Ganorrhynchus Susmilchii</i> .	————

PROTOZOA.—Radiolaria are locally abundant (Tamworth Beds). Foraminifera are unknown.

PORIFERA.—*Receptaculites*, an organism whose true affinities are still uncertain, but which is probably a sponge, occurs in abundance in the Murrumbidgee beds.

COELENTERATA.—Corals still retain the dominating position they held in the Silurian period. Of the Tabulata, *Halysites* was extinct, but *Favosites* and *Syringopora* continued to flourish, the latter in even greater abundance than before; the former is represented mainly by branching types. Of the Tetraeoralla, the genus *Diphyphyllum* occurs in large numbers, and is, perhaps, the most distinctive of the Lower Devonian corals; *Cyathophyllum* is still abundant, but *Mucophyllum*, *Heliophyllum*, and other typical Silurian genera have become extinct. The Cystiphyllidæ are more strongly represented, such genera as *Spongophyllum* and *Actinocystis* being abundant, but *Rhizophyllum* is absent. *Heliolites* (Octocoralla) is still very plentiful.

MOLLUSCOIDEA.—Brachiopods were locally abundant, particularly the genera *Spirifer* and *Chonetes*;

these occur in enormous numbers in some of the Murrumbidgee beds. *Atrypa* still lingers on, but *Pentamerus*, so characteristic of the Silurian period, is absent.

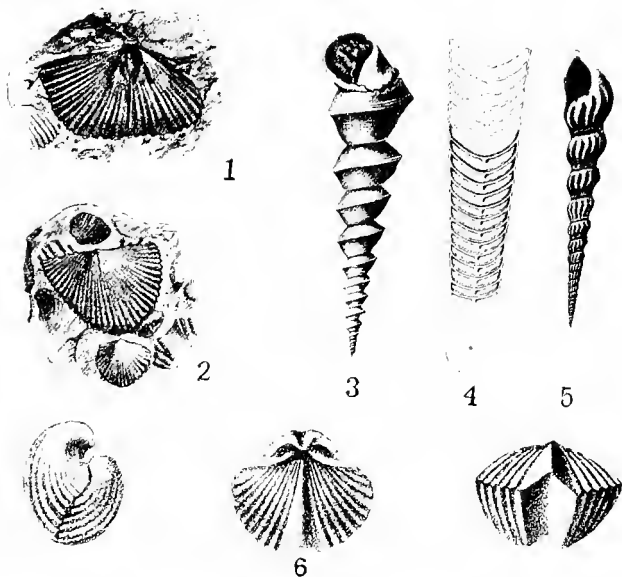


Fig. 23.

Lower Devonian Molluscoidea and Mollusca.

1 and 2. *Chonetes Calleni*. 3. *Marchisonia turris*. 4. *Orthoceras sublimidiatum*.
5. *Loranema anglicum*. 6, 6a, 6b. *Spirifer Yussensis*.

MOLLUSCA.—Cephalopods were large and numerous, the straight-shelled types, such as *Orthoceras*, still predominating. The Gasteropods were still represented mainly by long turreted forms (*Marchisonia*, &c.); but genera with depressed shells, such as *Belle*

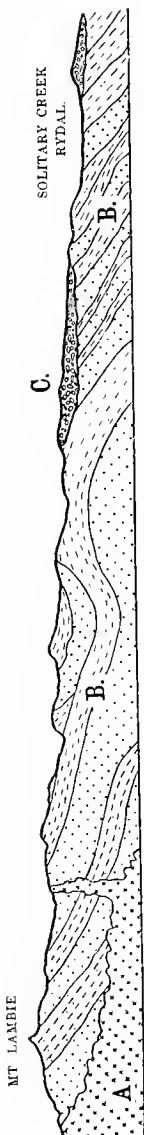


Fig. 24.

Section from Mount Lambie to Rydal. (After Wilkinson.)

A = Granite. B = Devonian quartzites and shales, with marine shells and *Lepidodendron Australe*.
C = Upper Marine conglomerates (Permo-Carboniferous).

rophon, become more common. Pelecypods appear to have been rare.

CRUSTACEA.—No Trilobites or other crustacea have yet been found.

VERTEBRATA.—The Murrumbidgee beds have yielded one fossil fish, *Ganorrhynchus*, which must have been about 5 feet in length, and belonged to the Dipnoi. This is the oldest recorded fish for New South Wales.

The Flora.—The lycopod, *Lepidodendron*, if the age assigned to the beds in which it occurs at Tamworth is correct, must have occurred in abundance. No other fossil plants are known.

Comparison of the Murrumbidgee and Tamworth Faunas.—The fossil fauna of the Murrumbidgee beds differs markedly from that of the Silurian period. There is an entire absence of such characteristic Silurian corals as *Halysites*, *Mucophyllum*, *Try-*

plasma, *Heliophyllum*, &c. On the other hand, *Diphyphyllum*, the most characteristic of the corals of the Murrumbidgee beds, is not abundant in Silurian strata. Similarly, the Brachiopod *Pentamerus* is absent from the Murrumbidgee beds. Such genera as are common to both formations are represented for the most part by different species.

While the fossil fauna of the Tamworth beds also differs from that of the Silurian period, it, in addition, displays a marked difference from that of the Murrumbidgee beds. Mr. W. S. Dun has pointed out that the Tamworth marine fauna, as a whole, is more closely related to that of the former than it is to the latter.

If the faunas of the Murrumbidgee and Tamworth beds were contemporaneous they certainly must have been provincial faunas, *i.e.*, were evolved in seas so isolated from one another that intermigration was very much restricted. The fossil lycopod, *Lepidodendron*, is unknown in both the Silurian strata and the Murrumbidgee beds; it is, on the other hand, very common in Upper Devonian strata. This raises the question as to whether the *Lepidodendron*-bearing strata of Tamworth and neighbouring parts of New England should not be correlated with the Upper Devonian beds.

THE UPPER DEVONIAN OR LAMBIAN SERIES.

Mount Lambie Beds.—The best known occurrence of Upper Devonian strata is that occurring along the western edge of the Blue Mountain Tableland. At

Mount Lambie (near Rydal) this formation has a thickness of not less than 10,000 feet, and includes shales, claystones, sandstones, and quartzites, the last named predominating. Marine fossils occur in abundance in some of the strata, and consist mainly of

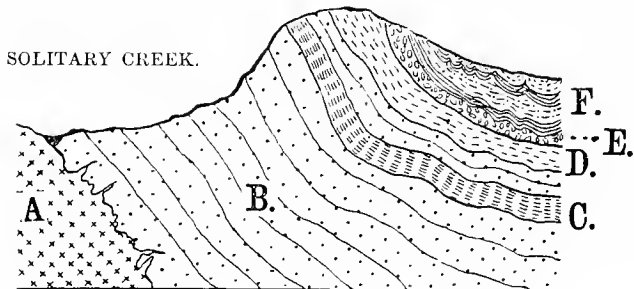


Fig. 25.

Section of Upper Devonian Strata, near Mount Lambie. (After David and Pitman).

- A = Granite. B = Quartzite, with *Spirifer disjuncta* and *Lepidodendron unsteadae*.
 C = Ferruginous shales. D = Grey shales, with obscure plant impressions.
 E = Conglomerate. F = Quartzites and shales, with *Lepidodendron*.

Brachiopods (*Spirifer*, *Rhynchonella*, *Lingula*) and Pelecypods, the former largely predominating. In these marine beds drift *Lepidodendron* also occurs.

At Capertee, some distance to the north-east of Mount Lambie, the formation consists of quartzites, conglomerates, claystones, and limestones. The limestone beds are usually thin, but sometimes thicken into solid masses of considerable extent; they contain fossil corals (*Favosites*, *Heliolites*, *Syringopora*, and *Cyathophyllum*). This occurrence of a coralline limestone in the Upper Devonian formation of New

SUCCESSION OF STRATA
along
GAP & SPRING CREEKS.

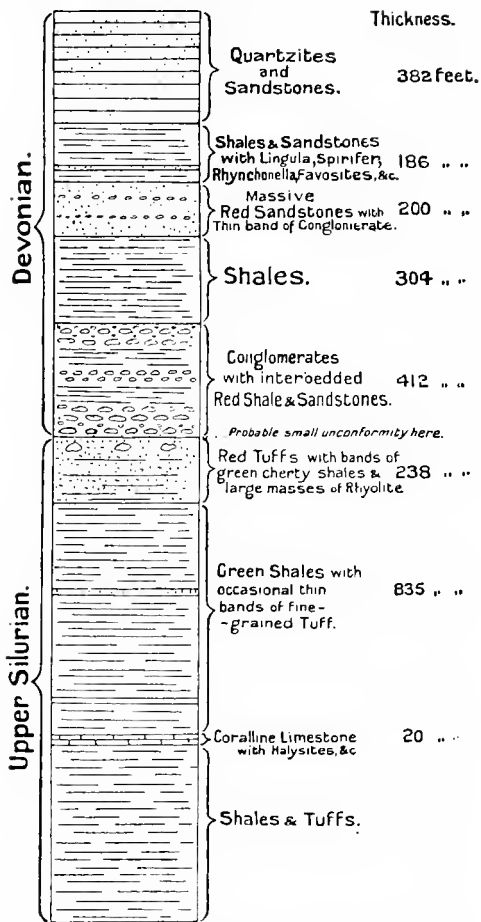


Fig. 26.

Section showing thickness and succession of Silurian and Devonian Strata at Gap Creek, Orange District.

South Wales is unusual. The whole series has been folded into symmetrical anticlines and synclines.

In the adjoining Mudgee district thick beds of tuff and contemporaneous lava-flows occur at the base of the series. These flows consist of rhyolite and augite-andesite. Conglomerates are also strongly developed in this region.

The Molong-Canobolas Beds.—Immediately to the west of the Canobolas Mountains the succession of strata shown in Fig. 26 occurs.

The Devonian strata shown represent only a portion of the original thickness, much having been removed by subsequent denudation. They rest unconformably upon the Silurian strata, and the basal conglomerates contain waterworn pebbles of the Silurian limestone. All the beds, with the exception of some of the shales, have a more or less red colour, the sandstones in particular presenting a typical "old red sandstone" appearance. Many of the strata exhibit current-bedding, ripple-marks, and annelid tracks. The whole series must, therefore, have been deposited in shallow water along a shore line. As is usual in New South Wales, the fossils are nearly all brachiopods, and these include *Spirifer disjuncta*, *Rhynchonella pleurodon*, and *Lingula gregaria*. Some plates of a placogonoid fish have also been found here. At Canowindra, some 30 miles to the south, similar Upper Devonian shales and sandstones occur, containing in one and the same stratum the fossil shell *Lingula gregaria* and the fossil plant *Lepidodendron*; these plant remains evidently drifted to their present



Fig. 27.
Inclined Devonian Quartzites, Gap Creek, near Orange.

position. At Wellington, about 60 miles to the north of the Molong locality, a massive series of Upper Devonian conglomerates, quartzites, and shales occurs, also containing *Spirifer disjuncta* and *Rhynchonella pleurodon*.

In the Parkes-Forbes district the Devonian system is represented by a much denuded series of quartzites, sandstones, and chocolate and greenish-grey coloured shales (Fig. 29). The thickness of the beds exposed to the east of Parkes exceeds 5,000 feet. A peculiarity of the series is the repeated alternation of quartzites and chocolate-coloured shales. Specimens of *Lepidodendron australe* and of fish-scales and plates (*Astroblepis*) are fairly common in these beds. From one locality the formation has yielded poorly preserved specimens of *Rhynchonella*, *Pterinea*, and *Orthis*.

Many other outcrops, some of them covering considerable areas and consisting of similar massive conglomerates, quartzites and shales, occur in various localities in the western districts of New South Wales. These occurrences have not yet been systematically examined, and have, in nearly all cases, been referred to the Upper Devonian, from their lithological character only. Mr. E. C. Andrews has quite recently mapped an extensive series of Upper Devonian strata in the Cobar district, lying immediately to the west of the Silurian mineral belt. They resemble the Mount Lambie beds in their lithological characters, and contain imperfectly-preserved brachiopod shells and crinoid stems.

South-Eastern District.—Extensive areas of similar strata occur in the south-eastern district extending at intervals from the Shoalhaven River to the Victorian border. In the County of Auckland these strata have a thickness of upwards of 1,200 feet. Here, in the Narrungutta and Yambulla Ranges, the beds are nearly horizontal, but on the Wolumla gold-field they have suffered considerable folding. In some of them ripple-marks and annelid tracks are not uncommon. On the Genoa River fresh-water or estuarine shales, which occur near the top of the series, have yielded the following fossil plants:—

Pecopteris obscura. *Archaeopteris Howitti.*
Sphenopteris Carnei. *Cordaites australis.*

These are the oldest fresh-water beds yet observed in New South Wales. Farther to the north, on the Pambula gold-field, a thick series of Upper Devonian strata is seen resting unconformably upon the Silurian beds. On the Yalwal gold-field, still further to the north, contemporaneous lava-flows and tuffs are associated with similar Upper Devonian strata; rhyolite and basalt flows apparently alternate with one another, and the former outcrop on a grand scale for miles along the Upper Danjera Creek, forming precipitous walls to the gorge. Fluxion and spherulitic structures are particularly well developed in the rhyolites. Certain belts of these Devonian strata have been impregnated with gold, along what are probably shear zones, and have been extensively mined for that metal.

UPPER DEVONIAN LIFE.

The following is a list of the more important fossils at present known from these beds:—

Hydrozoa—*Stromatopora*.

Actinozoa—*Heliolites*, *Favosites*, *Syringopora*
(three species).

Crinoidea—Crinoid stems.

Vermes—Annelid tracks.

Polyzoa—*Fenestella*.

Brachiopods—*Lingula gregaria*, *Spirifer disjuncta*,
Spirifer Jaqueti, *Rhynchonella pleurodon*, *Chonetes*,
Athyris, *Atrypa*, *Leptaena rhomboidalis*.

Pelecypoda—*Pteronites Pittmani*, *Leptodomus*,
Aviculopecten, *Pterinea*.

Gasteropoda—*Loronema*, *Murchisonia*, *Euomphalus*
Culleni, *Bellerophon*.

Pisces—Plates of placio-ganoid fish (? *Asterolepis*)

Filicales—*Pecopteris obscura*, *Sphenopteris Carnei*,
Archæopteris Howitti.

Lycopodiales—*Lepidodendron australe*.

Cordaiteæ—*Cordaites Australis*.

The fauna, so far as we know it, is for the most part a littoral one in which Brachiopods predominate. The two cosmopolitan species *Spirifer disjuncta* and *Rhynchonella pleurodon* are particularly abundant, certain beds being literally crowded with their shells. *Lingula* is also abundant at some localities. The sea-bottom where these brachiopod shells accumulated must have been not unlike the oyster-banks of the present-day. Pelecypods were numerous, and belonged largely to

the oblique-winged avienulids. The gastropods were less numerous, the long turreted forms of the Silurian and Lower Devonian now giving place to flattened types such as *Euomphalus* and *Bellerophon*. The Brachiopods and Mollusca, although numerous, do not seem to have attained large dimensions as individuals.

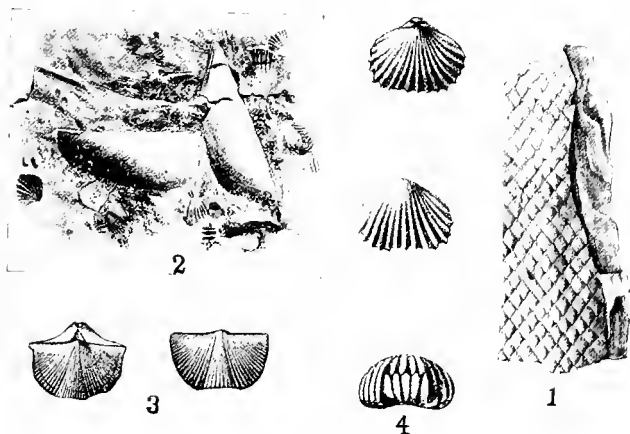


Fig. 30.

Upper Devonian Fossils.

1. *Lepidodendron australe*.
2. *Pteronites Pittmanii*.
3. *Spirifer disjunctus*.
4. *Rhyachonella pleurodon*.

The shallow waters of the Upper Devonian seas, constantly receiving large quantities of sediment from the neighbouring land, were unfitted for such organisms as crinoids and corals to live in, and, as one would expect, their remains are seldom found in these Devonian strata. Coralline limestones occur in the Capertee district, and probably represent temporary

local conditions of open and clear waters in which the coral polyps were able to flourish.

The absence of trilobites is not easy of explanation; they flourished abundantly in the Silurian, and as we find them also in considerable numbers in the Carboniferous, they evidently had not become extinct. The muddy waters of the Upper Devonian should have provided a suitable habitat for them. Very little collecting has been done in these strata, however, and they may still be found in them. Fragmentary fish remains have been obtained from several localities, but little is as yet known about the fish to which they belonged.

The Devonian Flora.—This flora is interesting as being the oldest yet discovered in Australia; it includes ferns, lycopods, and cordaitea. The occurrence of such widely different groups of land-plants living side by side in this period is a strong argument in favour of the existence of a terrestrial flora in the Silurian period, or even earlier. A long period of time must have been necessary for the evolution of such diverse types of plants as this flora displays. *Lepidodendron* is the most abundant and widely distributed of the Devonian plants, due, no doubt, to the fact that its trunks and branches were able to survive transportation by sea and to resist decomposition long enough to become water-logged and thus be buried in the Devonian marine sediments. The scarcity of the other members of this flora is due, no doubt, to the comparative absences of known fresh-water strata; the ferns found in the Genoa Creek beds were, no

doubt, just as widely distributed on the Devonian land surfaces as *Lepidodendron* was.

SUMMARY OF THE DEVONIAN PERIOD.

Our knowledge of the Devonian formation in New South Wales is so incomplete that it is difficult to make any broad generalisations as to the geographical conditions and earth movements of this period. The conclusions advanced here are therefore tentative, and will, no doubt, need considerable modification as fuller information becomes available.

It has been shown that Devonian strata of two different types occur in New South Wales, and that they have been referred to the Lower and Upper Devonian epochs respectively. Both the Upper and Lower series are unconformable with the Silurian strata, but their stratigraphical relation to one another is quite unknown, as no junction between them has yet been found, nor are both known to occur in one and the same district. In Victoria, however, the Upper Devonian strata (Mt. Tambora beds, Iguana Creek beds) rest directly upon the Middle Devonian beds of these localities, and the junction between them shows a marked unconformity. The Upper Devonian strata of Victoria, however, are all believed to be fresh-water beds. Judging by the known distribution of the Lower Devonian beds in New South Wales, the deformative movement which closed the Silurian period must have raised a considerable portion of the State above sea-level, leaving, however, at least two considerable areas still under marine conditions—one

in the south, stretching from the Murrumbidgee River southwards into Victoria, the other to the north, in what is now the Tamworth-Barraba district. The littoral deposits, whose deposition might reasonably be expected to have followed this extensive uplift, do not apparently exist, or if they do have still to be found; off-shore deposits, such as shales and limestones, are the prevailing rock types. Vulcanism was a pronounced feature, particularly at the beginning of the period, and continued intermittently throughout; the main centres of eruption seem to have been in the south.

As already pointed out, the fossil faunas of these two areas indicate that if they were contemporaneous the seas in which they lived could not have been in direct communication, but must have been separated from one another by a land barrier which prevented the new species evolved in either area from migrating freely to the other.

Marine life was abundant in these seas, and reference to the list of fossils already given will show that reef-building corals flourished; while, in the Murrumbidgee region, Brachiopods and the various groups of Mollusca were also well represented. From these beds the oldest vertebrates yet found in Australia have been obtained. These were primitive fish, belonging to a group called the Dipnoi; an allied genus, *Neoceratodus*, still survives in Queensland.

Assuming that the Upper Devonian strata were deposited later than the Lower Devonian strata, and that a marked unconformity exists between them in

New South Wales, as appears to be the case in Victoria, then a deformative movement must have followed the deposition of the Lower Devonian sediments. The wide extent of the Upper Devonian strata indicates that it must have been followed by an extensive subsidence, which allowed of the formation of broad, shallow epicontinental seas, in which the Upper Devonian sediments were deposited. The common occurrence of conglomerate, grits, and sandstones indicates the existence of considerable areas of dry land at no great distance to provide the necessary material for their formation; this supposition is supported by the presence of abundant drift-wood in the same strata. It is impossible, with our present deficient knowledge, to reconstruct the geography of New South Wales as it was at this time, but it seems probable that there existed an archipelago of large islands separated by broad, shallow epicontinental seas. An abundant marine invertebrate fauna, consisting of Brachiopods, Pelecypods, and Gasteropods, inhabited these seas. Vertebrate animals were represented by fish only, which appear to have been both large and numerous. That the neighbouring land was clothed with vegetation is shown by the abundant drift *Lepidodendron* which is found in these marine strata and the occurrence of plant beds near the Victorian border. These plants were nearly all Cryptogams (lycopods and ferns).

An alternative explanation of the relations between the Lower and Upper Devonian formations, however, suggests itself, and that is that the two formations

were deposited more or less contemporaneously, the former in an open but comparatively shallow epicontinental sea, at some distance from a shore-line; the latter in the shallow coastal waters of the same sea. The marked differences in the faunas of the two formations would be due in this case to the differences of environment. It has already been pointed out that the beds of the typical Murrumbidgee type and of the typical Mount Lambie type do not occur in one and the same districts; that fact lends some support to this view. The occurrence of *Lepidodendron australe* in the beds above the coralline limestones in the so-called Lower Devonian beds at Tamworth, and the occurrence of a coralline limestone with *Favosites*, *Heliolites*, and *Syringopora* in the Upper Devonian formations near Capertee, supply additional evidence. One would, of course, if this view were the correct one, expect to find formations somewhat intermediate in character between the characteristic Murrumbidgee and Mount Lambie types; these, however, may yet be found. Until further evidence is available it would be preferable, therefore, to use the terms Murrumbidgean and Lambian in lieu of Lower and Upper Devonian.

CLOSE OF THE DEVONIAN PERIOD (KANIMBLA EPOCH).

The close of this period was one of the great mountain-making epochs of New South Wales; and no part of the State, excepting the north-eastern section, has since been subjected to similar orogenic earth movements. Throughout the central and southern tablelands and throughout the western part

of the State the Ordovician, Silurian, and Devonian strata are strongly folded. Carboniferous strata are absent, and the strata of the succeeding period (Permo-Carboniferous) in those parts of the regions in which they occur rest upon the Devonian and earlier formations with a marked unconformity. These Permo-Carboniferous strata are either quite horizontal or have a very low angle of dip, and have not been folded; their present elevation above sea level is due to epeirogenic movements (vertical uplift) only. Throughout the greater part of this area the two lowest subdivisions of the Permo-Carboniferous series (the Lower Marine Series and the Lower Coal Measures) are absent, the Upper Marine Series resting directly upon the denuded edges of Devonian or older strata. It is apparent, therefore, that the orogenic movements which folded the Devonian strata in the region under consideration must have taken place before the Permo-Carboniferous strata were laid down, probably also before the Carboniferous sediments to the north were deposited. This latter opinion is supported by the fact that, when the Permo-Carboniferous seas invaded these regions, the Devonian strata had been so deeply denuded as to expose extensively the large granite bathyliths by which they had been intruded. (See Fig. 63). The folding, therefore, must have taken place either at the close of the Devonian or, at latest, early in the Carboniferous period, and was on such an extensive scale as to convert the greater part of New South Wales into dry land. For this mountain-making

period the name Kanimbla Epoch is suggested, and will be used in that sense in this account of the geology of New South Wales. The strata then folded now dip either to the east or the west, the axes of the folds striking nearly north and south, *i.e.*, approximately parallel to the existing coast line. The tangential thrust which produced this folding probably came from the east.

The folding was accompanied by the intrusion of numerous bosses and bathyliths of igneous rock. These rocks vary considerably in composition, but are all more or less acidic, and consist, for the most part, of granites and tonalites.

Some geologists are of opinion, however, that no earth movements of any great importance took place at the close of the Devonian period, and that it was not until the close of the Carboniferous period that the Upper Devonian strata were folded. This may be true for the north-eastern part of the State (New England) where considerable areas were covered by the sea during at least part of the succeeding Carboniferous period. But there is no doubt that the greater portion of the regions covered by the sea in New South Wales during the Upper Devonian Epoch became dry land at the close of the Devonian Period.

So far as the north-eastern part of the State is concerned, it is quite probable that no important crustal movements took place at all at the close of the Devonian Period, and that the subsidence which was taking place continued on uninterruptedly into the Carboniferous Period.

CHAPTER VIII.

THE CARBONIFEROUS PERIOD.

THE earth movements which closed the Devonian Period converted the greater part of New South Wales (as already stated) into dry land, the only exception being the north-eastern portion, now known as the New England Tableland. A considerable part of this region was covered by the sea during some part of the Carboniferous Period. In the southern and western parts of this area extensive deposits of Carboniferous marine and fresh-water beds occur, having their present southern and south-western boundary approximately parallel to the railway line from Newcastle to Narrabri, and at no great distance from it. The only known outcrop of Carboniferous strata south of this line is the small inlier surrounded by Permo-Carboniferous strata at Pokolbin.

The Carboniferous formation in New South Wales has been subdivided into:—

- (a) The Upper Carboniferous, with *Lepidodendron Veltheimianum* and *Rhacopteris*.
- (b) Lower Carboniferous with *Lepidodendron australe*.

Lower Carboniferous.—Considerable thicknesses of strata, occurring in the New England district, have been referred to the Lower Carboniferous Period

because of a supposed lithological resemblance to a formation in Queensland, known as the Gympie Series. Some of these strata have been traced across the border into Queensland, and have been found to be continuous with some of the so-called Gympie beds of that State. Certain of the strata included in the Gympie series in Queensland are undoubtedly of Carboniferous age; some are probably of Permo-Carboniferous age; while other strata which have been referred to in this series are very probably older than Carboniferous, perhaps in some cases as old as Ordovician; the absence of fossils in many localities makes a correct determination difficult.

No marine fossils have yet been obtained from most of the so-called Gympie beds in New South Wales, and their reference to the Lower Carboniferous epoch, based entirely on lithological resemblances of strata in Queensland, whose geological age is so very doubtful, is not conclusive. As some of them have Permo-Carboniferous strata resting unconformably upon them, as, for example, at Ashford, near Inverell, these cannot, of course, be younger than Carboniferous.

The fossil plant *Lepidodendron australe* has been obtained from some of these beds, but as this fossil is very common in Devonian strata in the other parts of the State, its occurrence, in the absence of other fossils, might more justly be taken to indicate a Devonian age for such beds. Until detailed surveys have been carried out in this region no confident opinion can be expressed as to the geological age

of many of the so-called Lower Carboniferous (Gympie) beds, but the balance of evidence is in favour of the Devonian age for at least some of them. Quite recently some of the so-called Gympie beds of northern New England have been shown to be of Permo-Carboniferous age.

Upper Carboniferous Series. These strata are extensively developed on the watersheds of the Karuah, Williams, and Paterson Rivers, which are all tributaries of the Hunter River, draining the southern slopes of the New England tableland. According to Mr. Jaquet, they have a thickness of at least 19,000 feet. They are partly marine and partly fresh-water in origin, and consist of tuffaceous sandstones, claystones, limestones, conglomerates, cherty shales, with contemporaneous lavas and tuffs. Some of the beds contain numerous marine fossils of undoubted carboniferous age, while in the fresh-water beds abundant plant remains are found. The marine beds are well developed in the neighbourhood of Clarence Town, where they consist of fossiliferous shales and sandstones interstratified with coarse-grained arkose-sandstones and tuffs; limestones occur, but are not very thick, and, when followed in the direction of their strike, pass rapidly by insensible gradations into calcareous shales; oolitic structure is not uncommon. Fresh-water beds occur interstratified with the marine beds more or less throughout the series, increasing in importance towards the top, where they entirely replace the marine beds. These fresh-water beds consist of shales and tuffaceous sandstones, with thin

seams of inferior coal. Throughout the Upper Carboniferous epoch vulcanicity was a marked feature, as evidenced by the numerous thick beds of tuff and lava which occur over wide areas, interstratified with both the marine and fresh-water sediments. In the Clarence Town and Paterson districts no less than twelve successive lava flows occur, ranging individually up to 500 feet or more in thickness (Fig. 31.).

These volcanic rocks comprise rhyolites, rhyolite-glass, and hypersthene-andesites with their corresponding tuffs. Some of the latter are very coarse-grained, with blocks up to 3 feet in diameter embedded in them; they contain also water-worn fragments of older rocks, and merge gradually into arkose-sandstones. At Bulladelah one of the rhyolite flows has, by the action of thermal springs, been altered into Alunite (hydrous sulphate of alumina and potash); this has been quarried on a large scale for the manufacture of alum. Another feature of possible economic importance is the occurrence of numerous beds of titaniferous magnetite interstratified with the Upper Carboniferous Series. These beds are of sedimentary origin, the magnetite having associated with it a variable proportion of quartz and felspar grains, and they merge by insensible gradations into ordinary tuffs and arkose-sandstones. This iron ore varies considerably in composition, containing 36 per cent. to 50 per cent. of metallic iron, 10 per cent. to 28 per cent. of silica, and 3 per cent. to 16 per cent. of titanie acid. Professor David has suggested that these beds have been formed by wave-

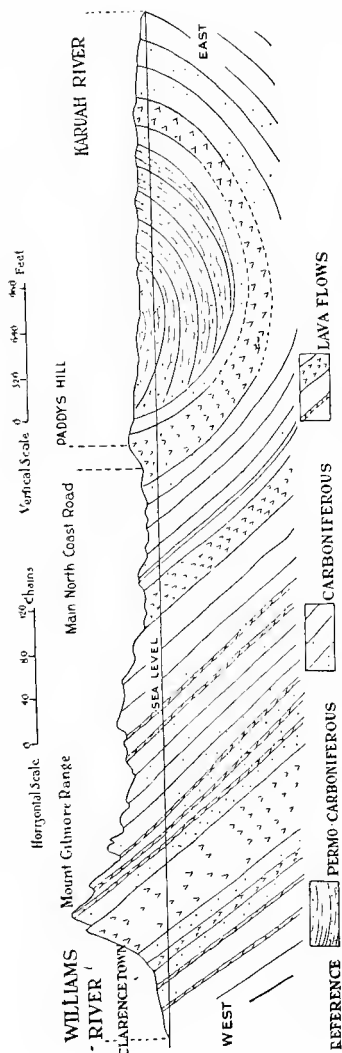


Fig. 31.

Section of Carboniferous Strata from Clarencetown to Karuah River. (Jaquet.)

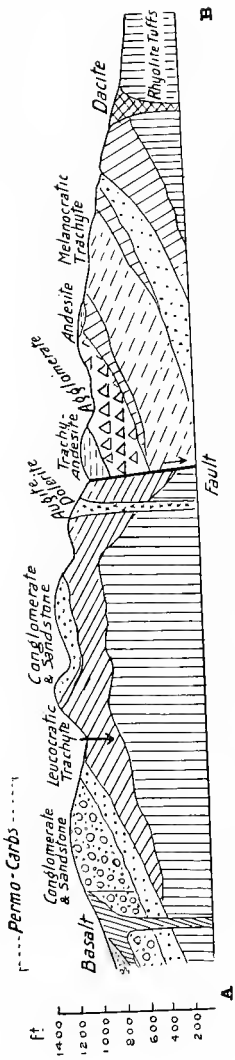


Fig. 32.

Section near Pokolbin, N.S.W., showing the succession of Carboniferous Lavas. (Walkom and Brown).

action on a sea-beach, mechanically concentrating the grains of magnetite contained in the volcanic ash, so abundantly ejected during this period.

At Pokolbin, some miles to the south of West Maitland, an "inlier" of these Upper Carboniferous strata occurs, entirely surrounded by strata of Permo-Carboniferous age; this inlier consists of rhyolite lavas and tuffs, trachyte lavas and tuffs, conglomerates, chocolate shales, tuffaceous sandstones, and andesites deposited in the order named (Fig. 32). The order of extrusion of the lavas for this locality has apparently been from acid to intermediate, viz., first rhyolites, then trachytes, and finally andesites. Further outcrops occur also along the western edge of the New England tableland, as for example near Barraba, where they consist of conglomerates, sandstones, shales, and limestones, with which are associated rhyolites and rhyolite tuffs. These beds contain similar marine fossils to those at Clarence Town. An extensive development of these acid lavas and tuffs occurs further to the north, in a belt running parallel to and west of the Northern railway line; they also underlie the Permo-Carboniferous rocks in the Drake District. Marine Carboniferous strata also outcrop on the coast from Port Stephens to Port Macquarie.

CARBONIFEROUS LIFE.

(a) *The Flora*.—The Flora is well preserved, much more so than that of the Devonian Period already

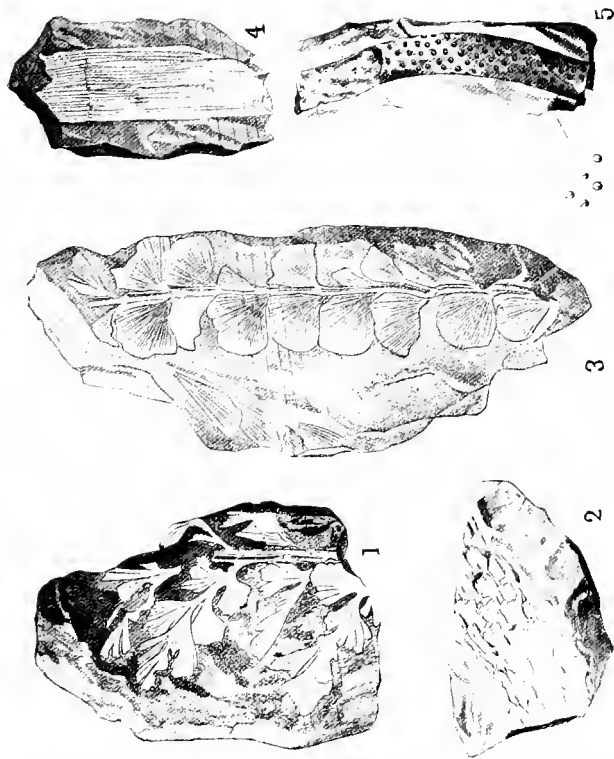


Fig. 33.

Carboniferous Plants.

1. *Archonopteris Wilkinsii* (Feist).
2. *Lepidodendron Volkmanianum*.
3. *Rhaptopteris (Auctinites) inequilateralis*.
4. *Catanantes radiatus*.
5. *Cyclasphyra australis*.

described. It consists entirely of Cryptogams, and includes the following species:—

Equisetaceæ.—*Calamites radiatus*.

Lycopodiaceæ.—(?) *Lepidodendron australe*, *Lepidodendron veltheimiamum*, *Lepidodendron volkmanniamum*, *Cyclostigma australe*.

Filicaceæ.—*Rhacopteris* (*Aneimites*) *inequilatera*, *Rhacopteris intermedia*, *Rhacopteris septentrionalis*, *Archaeopteris Wilkinsoni*, *Cardiopteris polymorpha*.

The geological range of *Lepidodendron australe* is uncertain; that it was abundantly present during the Devonian Period is unquestioned, but whether it lived on into the Carboniferous Period is very doubtful. It has never been found associated with the other members of the flora listed above, neither has it been found associated with marine beds containing a typical Carboniferous marine fauna. The beds in which it occurs, as already pointed out, in the absence of other fossils might more reasonably be referred to the Devonian Period. The most abundant and characteristic fossil plant of the Carboniferous Period is *Rhacopteris*, and from it the flora as a whole has been termed the *Rhacopteris Flora*.

(b) *The Fauna*.—This, as far as we know it, is entirely a marine invertebrate fauna, consisting largely of Brachiopods, Polyzoa, Gasteropoda, Trilobites, and Corals, &c. The Brachiopods appear to have largely preponderated, but so little collecting has been done that generalization is difficult. The follow-

ing is a list of the more important genera and species so far described:—

Actinozoa.—*Amplexus*, *Zaphrentis Culleni*, *Lophophyllum corniculum*, *Campophyllum columnare*, *Cyathophyllum Davidis*, *Michelinia*, *Lithostroton*.

Crinoidea.—*Actinocrinus*, *Pericchocrinus*.

Blastoidea.—*Metablastus* (?)

Polyzoa.—*Fenestella*, *Polypora*.



Fig. 34.

A Carboniferous Trilobite.
Phillipsia dubia.

Brachiopoda.—*Spirifer striata*, *Spirifer bisulcata*, *Orthis* (*Rhytidomella*) *australis*, *Orthis* (*Schizophoria*) *resupinata*, *Leptæna rhomboidalis*, *Productus semirciculatus*, *Productus punctatus*, *Productus cora*, *Chonetes papilionacea*, *Orthotetes cremistria*, *Athyris planosulcata*, *Cyrtina carbonaria*, *Rhynchonella pleurodon*, *Strophalosia*.

Pelecypoda.—*Ariculopecten*, *Edmondia*, *Entolium*, *Pteronites*.

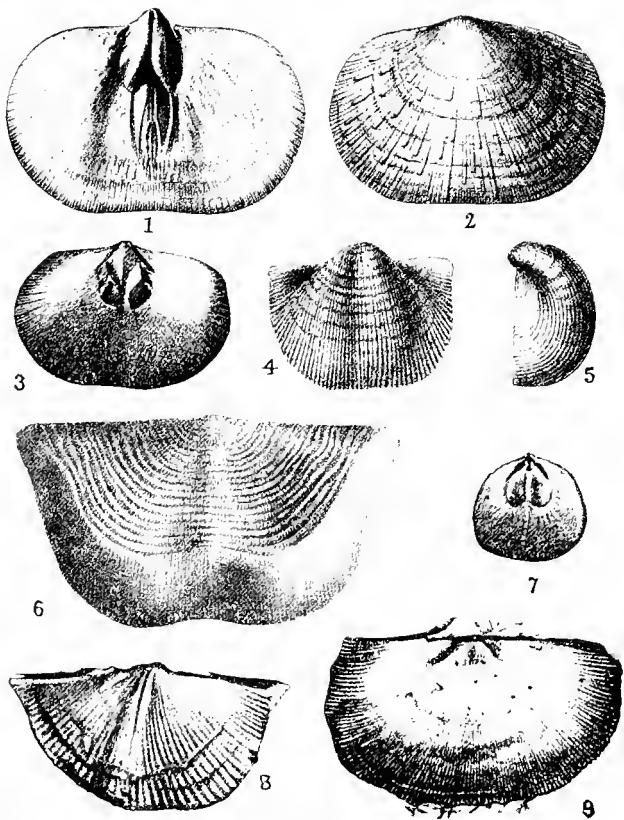


Fig. 35.

Carboniferous Brachiopods.

- 1-3. *Orthis (Schizophoria) vesupiana*. 4-5. *Productus scuireliculatus* (Martin).
 6. *Leptaena ualoga* (Phillip). 7. *Orthis (Rhipidomella) Australis*. 8. *Spirifer striata*.
 9. *Orthotetes cruciaria*.

Gasteropoda.—*Euomphalus pentangulatus*, *Loxonema babbindonensis*, *Bellerophon*.

Cephalopoda.—*Orthoceras*.

Trilobita.—*Phillipsia*, *Griffithides*.

PROTOZOA.—Neither Foraminifera nor Radiolaria appear to have been abundant.

ACTINOZOA.—Corals, so far as is known, were only moderately abundant; most of those found built simple coralla and belong to the Tetracoralla. The Tabulata, which were so strongly represented in the Silurian and Devonian Period, are here represented by one genus only (*Michelinia*).

ECHINODERMATA.—Crinoids, although less abundant than in the Silurian Period, are still present in considerable numbers. This formation contains the first and only recorded Blastoid from this State.

MOLLUSCOIDEA.—Polyzoa are numerous, and most of those found belong to the Fenestellidæ, the most characteristic Palæozoic representatives of this class. Brachiopods are present in great abundance and dominate all the other invertebrates; the families *Strophomenida*, *Orthida*, *Productida* and *Spiriferida* are all well represented. *Rhynchonella pleurodon*, which lived in such countless numbers in the Upper Devonian Epoch, still survives, but is not abundant.

MOLLUSCA.—All the important classes were represented, but were quite subordinate in importance to the Brachiopods.

CRUSTACEA.—The Trilobites still lingered on, but were represented by but two genera, both of which

are small in size. This unique and important group of Palæozoic organisms became extinct at the close of this period.

SUMMARY.

The crustal movements which closed the Devonian Period probably converted the greater part of New South Wales into dry land. Most of it remained above the sea during the succeeding Carboniferous Period, but in the north-eastern part of the State a subsidence began at the beginning of this period which allowed of an extensive transgression of the sea taking place in that region. Much detailed mapping of the Carboniferous formation will have to be done, however, before the extent of this transgression is at all accurately known. Subsidence continued more or less throughout this period, but repeated oscillations in the downward movement brought about alternate marine and fresh-water conditions, particularly towards its close. The sea contained an abundant invertebrate fauna, while the land supported a well-developed cryptogamous flora. The subsidence was accompanied by intense and widespread vulcanicity, and from numerous centres of activity in the north-eastern part of the State extensive lava flows and deposits of volcanic ash were produced. These eruptions continued at intervals throughout the greater part of the Carboniferous Period, but were most pronounced towards its close.

CHAPTER IX.

PERMO-CARBONIFEROUS PERIOD.

A TYPICAL Permian formation, analogous to that of the Northern hemisphere, does not occur in Australia, its place being taken by the so-called Permo-Carboniferous system. This name, which was first suggested by Mr. R. Etheridge, Jr., has been applied in Australia to a thick series of marine and fresh-water beds which follow the Carboniferous formation described in the last chapter, and which are in turn overlain by fresh-water Triassic strata. In New South Wales this Permo-Carboniferous system has a maximum thickness of about 17,000 feet, and includes both marine and fresh-water sediments. The marine beds contain an abundant fauna which, taken as a whole, is essentially different from that of the underlying Carboniferous strata, and which has affinities with both the Carboniferous and Permian marine faunas of the Northern hemisphere. The fresh-water beds interstratified with these marine sediments contain a fossil flora absolutely different from that of the underlying Carboniferous beds; this flora displays a decidedly Mesozoic aspect, nevertheless it is quite different from that preserved in the overlying Triassic strata.

The Permo-Carboniferous system is strongly developed in the eastern part of New South Wales, especially in what might be called the central-eastern portion of the State. Here it occurs in the form of

a great basin extending from the coast to the western edge of the Blue Mountain tableland, and from the Illawarra district northwards to the southern edge of the New England tableland. Throughout the greater part of this area the Permo-Carboniferous strata are overlain by Triassic beds; a continuous outcrop of them occurs, however, around the edge of the basin, excepting along that part of the coast between Coal-cliff and Lake Macquarie. In addition to this main basin, Permo-Carboniferous strata are extensively developed along both the eastern and western flanks of the New England tableland, but are quite absent in the south-eastern and in the western parts of the State.

Where the Permo-Carboniferous formations comes in contact with the underlying Carboniferous, as in the Hunter River district, the two systems seem to be separated by an unconformity, and there is frequently considerable overlap of the entire strata of the Permo-Carboniferous on the Carboniferous, so that in many places the basal beds are entirely concealed from view by the later beds.

The following subdivision of the Permo-Carboniferous system is used in New South Wales:—

	Maximum Thickness.
Upper Coal-measure Series ..	1,500 feet
Dempsey Series	3,000 ..
Middle Coal-measure Series ..	1,700 ..
Upper Marine Series	6,400 ..
Lower Coal-measure Series ..	300 ..
Lower Marine Series	4,800 ..
Total	<u>17,700</u>

(A).—THE LOWER MARINE SERIES.

The Hunter River District.—This, the lowest subdivision of the Permo-Carboniferous system, has its greatest development in the Hunter River district, where it attains a maximum thickness of about 4,800 feet. The following strata occur (in descending order).

Farley stage—		Thickness.
Marine sandstones		800 feet
Ravensfield sandstones		15 ..
Lochinvar stage—		
Tuffaceous and calcareous shales and cherts (with abundant Polyzoa and Foraminifera) ..	700	..
Amygdaloidal basalt flow	100-500	..
Harper's Hill sandstones and conglomerates (passing into andesite in places)	200	..
Tuffaceous shales (with glacial erratics and two contempo- raneous basaltic lava flows) ..	2,500	..
Massive sandstones, with plant remains	50	..
Glacial beds with numerous striated boulders	200	..

The basal beds consist of shales and sandstones containing numerous ice-striated pebbles and boulders. These are not in any sense boulder-clays or till, but are ordinary sediments into which, during their de-

position, glaciated pebbles have been dropped by floating ice. It might be mentioned here that this is the probable origin also of the striated boulders and erratics which occur on several higher horizons in the Permo-Carboniferous system in New South Wales.



Fig. 36.

Photograph of a Glacial Erratic (Granite) occurring in Upper Marine Strata, near Branxton, New South Wales. (David.)

These glacial beds grade upwards into massive sandstones containing plant remains. Then follows a series of shales with occasional glacial erratics, and containing abundant marine fossils. These beds are

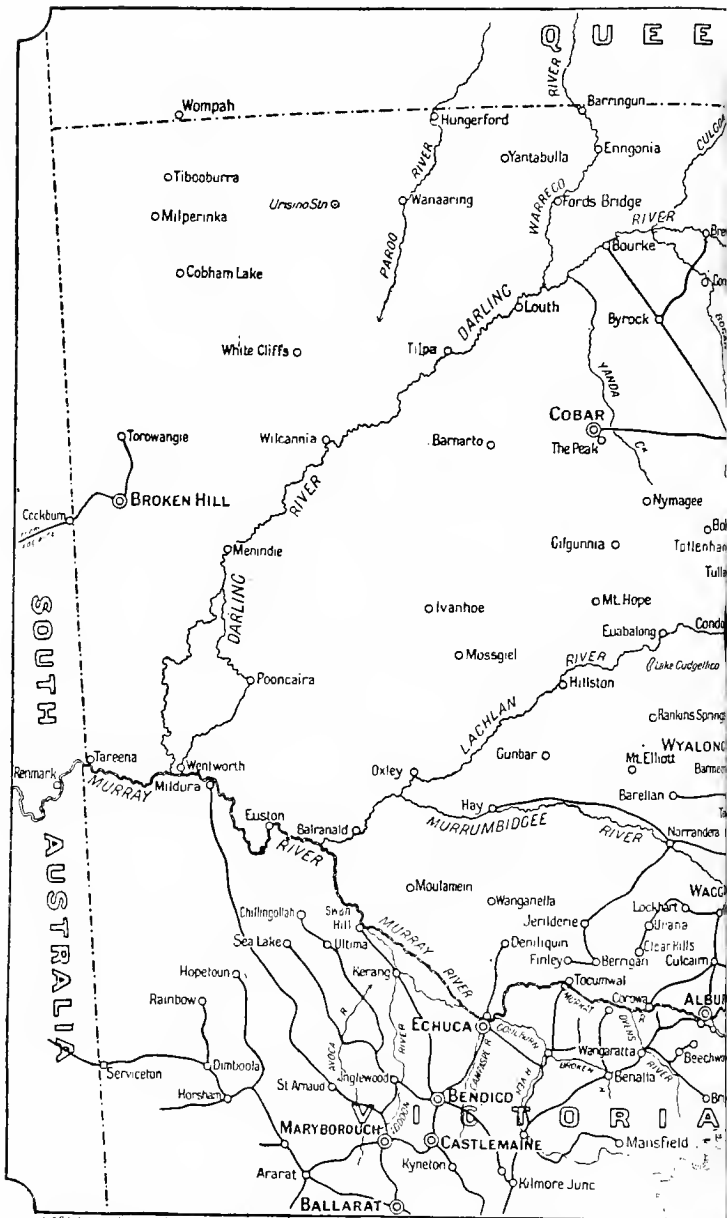


Fig. 37.—Map of New South Wales, showing



Climate area covered by the Lower Marine Sea.

about 2,500 feet thick, and include several contemporaneous lava flows. The tuffaceous sandstones and conglomerates which come next are typically exposed at Harper's Hill and in the railway cuttings at Allandale. They contain abundant fossil shells, some of which, such as *Eurydesma*, *Keenia*, *Aviculopecten*, &c., attain a considerable size. In close association with the *Eurydesma* beds occur andesitic lava flows and tuffs, typically developed at Blair Duguid, to the south of Allandale. The Harper's Hill beds are followed by a series of basic lavas and tuffs ranging from 100 to 500 feet in thickness, the latter containing fossil plants. This volcanic series is well exposed at Mount View, still further to the south of Allandale, and is overlain by about 700 feet of soft calcareous shales, some of which are crowded with exquisitely preserved fossil Polyzoa (*Fenestella*, *Polypora*, *Stenopora*) and Foraminifera (*Nubecularia*, &c.). These calcareous shales are more or less tuffaceous; they close the Lochinvar stage and are succeeded by the Ravensfield sandstones, the basal beds of the Farley stage. This bed of sandstone, although not more than 15 feet in thickness, is so persistent, that in one place it can be traced for a distance of 20 miles; it contains, in places, numerous fossils, the most characteristic of which are the genera *Goniatites* and *Edmondia*. Some beautiful starfish are also obtained from this stratum. The remaining beds of the Farley stage have a thickness of about 1,000 feet, and consist mainly of sandstone; in some of them marine fossils are very abundant.

Near Raymond Terrace the Lower Marine series includes some fresh-water beds which occur at about the same horizon as the *Eurydesma* beds of Allandale. These contain abundant fossil ferns (*Gangamopteris*) and a coal seam about 10 feet thick, known as Garrett's Seam.

The Northern Rivers District.—Extensive outcrops of Lower Marine strata are known to occur at various localities between the Hunter River and the Queensland border, notably on the watershed of the Macleay River, and about the head waters of the Upper Clarence River. The former area extends from the coast at the mouth of the Macleay River westward to the eastern fall of the New England tableland; but very little is at present known as to its real extent. In his account of the Drake goldfield, Mr. E. C. Andrews has described the occurrence of Lower Marine strata, associated with which is an extensive series of andesitic lavas and tuffs, the whole resting unconformably upon an older series of acid lavas and tuffs; the latter are, probably, of Carboniferous age. The Permo-Carboniferous strata in this region have been extensively folded, and have been intruded by at least two separate granite intrusions.

Mr. J. E. Carne has quite recently proved the existence of similar Lower Marine strata in the Emmaville district.

Overlapping of the Lower Marine Beds.—In the Hunter River district, where the northern edge of the Permo-Carboniferous basin occurs, the Lower Marine beds, as well as the Lower Coal Measures which follow

them, dip south and west under the later members of the system, but fail to reappear again, either on the southern or the western edges of the Permo-Carboniferous basin. Both series, therefore, have evidently been overlapped by the Upper Marine series, which in these regions rests directly, and at the same time unconformably, upon strata of Devonian age (see Fig. 63). Just how far to the south and south-west this overlap takes place is unknown. The probable position of the shore-line of New South Wales during the Lower Marine epoch is shown in Fig. 37. The positions shown are, of course, mere approximations, as there may be other areas of Lower Marine strata at present unknown.

(B).—THE LOWER COAL-MEASURE SERIES.

Hunter River District.—In this district the lower Coal Measures are generally referred to as the Greta Coal Measures, and have a thickness of from 150 to 250 feet. They comprise fresh-water shales, sandstones, and conglomerates, and contain two important coal seams. The lower coal seam is known as the Homeville Seam; it varies from 3 to 11 feet in thickness and contains a hard, bituminous coal. In the South Greta Mine the base of this seam consists of kerosene shale. The upper seam, called the Greta Seam, varies from 14 to 32 feet in thickness, and is undoubtedly the finest seam of coal yet found in Australia. The coal is very hard, bright, and bituminous, and shows remarkable uniformity in composition throughout the district in which it occurs; it is of

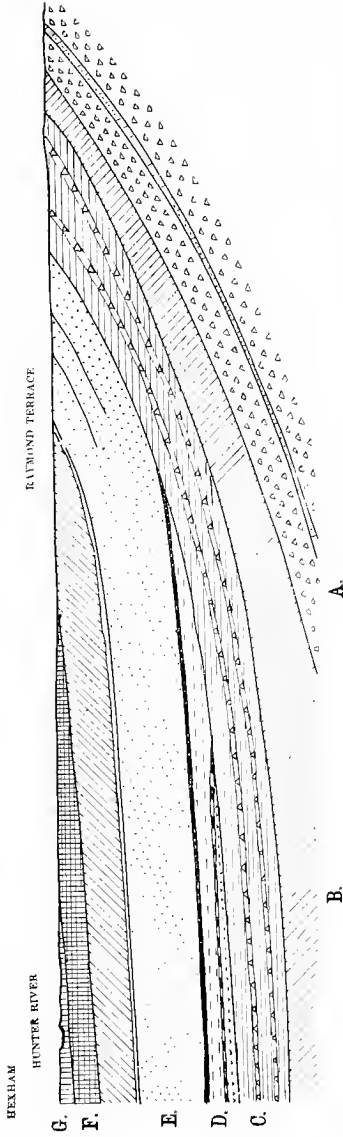


Fig. 38.

Section of Permo-Carboniferous Straata near Raymond Terrace, Hunter River District, showing an overlap of the Upper Marine Series upon the Lower Coal Measures. (After Davit.)

A = Carboniferous rhyolites and tuffs. B = Carboniferous tuffaceous shales and sandstones, with *Rhatapheris*. C = Lower Marine Series, with contemporaneous lava flows. D = Lower Coal Measures. E = Upper Marine Series. F = Tomago Coal Measures. G = Dempsey Series.

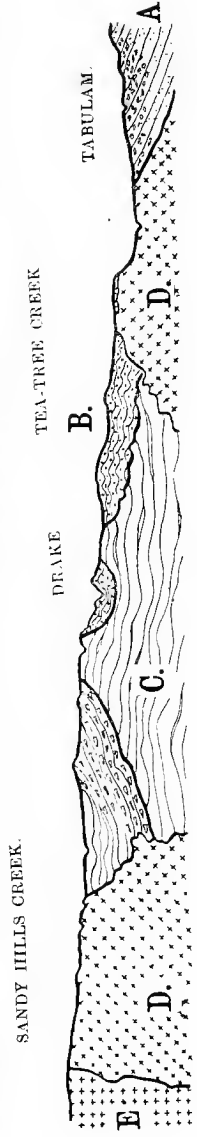


Fig. 39.

Section across the Drake Goldfields, New England (After Andrews.)

A = Clarence Series (Trias-Jura). B = Lower Marine Series (Permo-Carboniferous). C = Rhyolite (Carboniferous?). D = Acid Granite. E = Sphene Granites-Porphry.

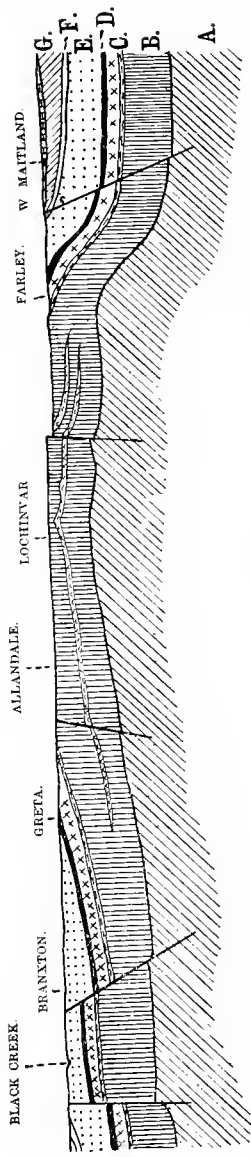


Fig. 40.
Section across the Lochinvar Anticline. (After David.)

A = Carboniferous shales, slyolites, and tufts. B = Lower Marine Series—Lochinvar stage. C = Lower Marine Series—Farley beds.
 D = Lower Coal Measures. E—Upper Marine Series—Brankston beds. F = Upper Marine Series—Muree beds.
 G = Upper Marine Series—Crimoidal shales.

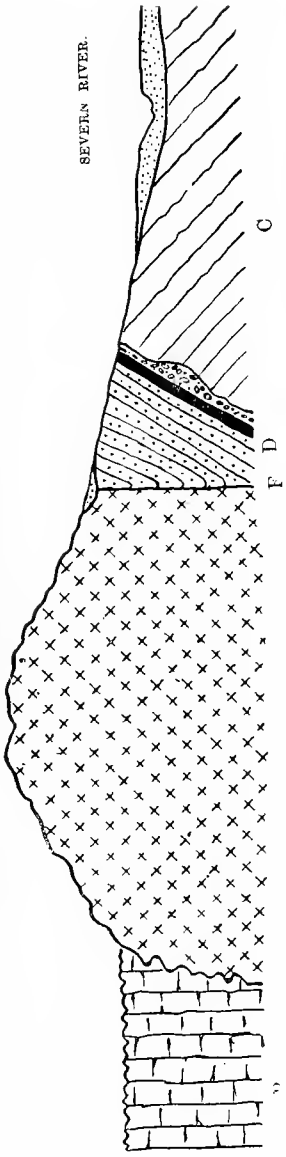


Fig. 41.
Section of the Ashford Coal Basin near Inverell. (David.)

A = Granite. B = Limestone (? Devonian or Carboniferous). C = (?) Gympie beds. D = Lower Coal Measures, with a 30-foot coal-seam.
 F = Probable fault.

excellent quality for steam, gas, and household purposes. In some places it merges into a cannel coal, and occasionally into kerosene shale. In the sandstones and shales forming the roof of this seam stems of trees of considerable size occur.

A bed of conglomerate, containing white and green pebbles, which overlies the bottom seam of coal, forms a characteristic "persistent horizon" which has been very useful in mapping the outcrop of these coal-measures. On the eastern side of the anticline a continuous line of collieries extends from West Maitland to Cessnock, nearly all of which have been opened up during the past few years. As these coal seams are not horizontal, but dip at angles ranging up to 50° , or even more in some places, their depth below the surface must rapidly increase in the direction of the dip, when the latter is considerable. Using a limit of 4,000 feet as the vertical depth at which coal seams can be profitably worked, Professor David has estimated that these two seams exist at a workable depth over an area of 158 square miles, and contain a gross available quantity of 1,893,000,000 tons of coal.

A rich fossil flora has been preserved in the shale beds, and includes the genera *Gangamopteris*, *Glossopteris*, *Sphucnopteris*, *Nocggerathiopsis*, and *Dadoxylon*; of these the first is the most abundant.

New England Tableland.—The Lower Coal-measures extend northwards along the western fall of the New England Tableland towards the Queens-



Map of Sydney (Copyright)

2.
 a covered by the Lower Coal Measure Swamps.

land border. They are known to outcrop in the parish of Tangorin (county of Durham), where they appear to have been much disturbed. From there the outcrops trend northwestward past Muswellbrook, where a fine seam of coal 15 feet in thickness is now being opened up. At Wingen the Greta Coal Seam is on fire, and has been burning for probably 1,000 years or more. Still further to the north at Ashford, near Inverell, a long narrow coalfield occurs about a quarter of a mile wide and extending northward nearly to the Queensland border.

Here the Lower Coal-measures have a thickness of over 400 feet, and include a fine coal seam 27 feet in thickness and of good quality. These beds have a dip of 40° and rest unconformably upon a series of highly inclined slates which have been referred to the Carboniferous Period. It is quite possible that these latter beds are of Devonian age. The fossil plants associated with the coal seams here are similar to those of the Greta Series. At Wilson's Downfall, near Tenterfield, deposits of graphite occur, associated with slates and tuffs, all of which have been intruded by granite. The graphite deposit has resulted from the alteration of a dirty coal seam by the granite intrusion. These beds probably belong to the Lower Coal Measures.

Illawarra District.—Fresh-water beds containing coal seams have been found underlying the Upper Marine Series at several localities immediately to the south of the Shoalhaven River. They vary from a few feet up to 150 feet in thickness, and rest uncon-

formably upon tilted Devonian strata. Near the head of the Clyde River these beds outcrop at an altitude of 1,300 feet, and include two coal seams, the upper one of which is about 5 feet thick (including bands). Thin layers of kerosene shale occur near the top of this seam. Similar fresh-water beds occur elsewhere in the district, but they have no great thickness, and the coal seams are either poor or absent. The formation, as a whole, appears to occur in the form of small isolated basins rather than to be continuous over any considerable area, and as coal-measures they appear to have very little commercial value. These measures have been correlated with the Lower Coal Measures of the Hunter River district, but there is some doubt as to whether they are co-extensive with them. Assuming that they are, the areas occupied by the lakes of the Lower Coal Measures epoch were probably somewhat as shown in Fig. 42.

(C).—THE UPPER MARINE SERIES.

This series extends over a wider area, perhaps, than any of the other subdivisions of the Permo-Carboniferous Systems in New South Wales, and outcrops all round the edges of the main coal basin. A description of its occurrence in the Northern, Southern, and Western Coal-fields will serve to give a general idea of the main features.

Hunter River District (Northern Coal-field).—The Upper Marine Series here attains a maximum thick-

ness of 6,000 feet, and consists of the following strata:—

<i>Crinoidal Stage</i>			feet.
Chœnomya Beds	..	..	100
Crinoidal shales	..	..	2,900

Muree Stage

Conglomerates and sandstones	..	400
------------------------------	----	-----

Branxton Stage

Marine shales, sandstones, and conglomerates (with erratics)	..	3,000
--	----	-------

(a) *The Branxton Stage*.—These beds consist mainly of sandstone and shale, in which marine fossils, particularly the Fenestellidæ family of the Polyzoa, are very abundant; glacial erratics are also very numerous. These latter range up to 5 tons in weight, generally consist of granite, and some of the smaller ones are distinctly striated. One of these erratics is shown in Fig. 36. The position in which it rests, poised on edge, and the way in which it seems to have indented the underlying shales, shows that it was probably dropped from floating ice into a bed of soft marine mud and left standing in the position in which it is now seen. One of the few fossil corals which occur in the Permo-Carboniferous strata, viz., *Trachypora*, occurs abundantly near the top of this stage.

(b) *The Murce Stage.*—The lowest stratum is a calcareous conglomerate, containing numerous small and occasionally large glacial erratics and an abundance of marine fossils. Its hardness and resistance to weathering cause it to make a bold outcrop. This bed is usually about 3,000 feet above the Greta Coal measures, and passes upward into a series of massive calcareous sandstones about 400 feet in thickness, in which a small brachiopod (*Strophalosia*) occurs in great numbers.

(c) *The Crinoidal Stage.*—The strata on this horizon are mainly shales, and, as the name implies, contain abundant remains of Crinoids. The thickness varies from 1,500 to 3,000 feet, and they terminate upwards in beds of hard cherty shales called the *Chonomya Beds*, on account of the number of pelecypods of that name which they contain.

The Lithgow-Capertec District (Western Coal-field).—The Permo-Carboniferous formation here has a total thickness of from 800 to 1,600 feet as compared with a thickness of over 15,000 feet in the Hunter River district. The Lower Marine Series and the Lower Coal-measures are entirely absent, while the Upper Marine Series, the oldest subdivision represented, rests unconformably upon highly tilted Lower Palæozoic strata. It seems evident, therefore, that this region was dry land undergoing denudation during the time the absent members of the formation were being deposited elsewhere. A fairly rapid subsidence towards the latter part of the Upper

Marine epoch, however, allowed the sea to transgress much farther westwards than had been the case in the earlier part of the period. That the subsidence was fairly rapid is indicated by the thick coarse conglomerates which occur at the base of the Upper Marine Series in the western district. This is a typical basal conglomerate produced by the waves working over the regolith as the sea advanced on the land. The boulders in it are mainly granite and quartzite, derived from the older rocks upon which the conglomerate rests; the material cementing the boulders together is frequently granite sand (arkose conglomerates). These conglomerates are of considerable thickness, with increasing coarseness towards the lowest stratum, where occasional boulders of quartzite several tons in weight occur. It has been suggested that these large boulders have been transported by floating ice, but as this is a typical littoral deposit laid down along an old shore-line, and as the boulders appear to have been derived from the underlying and adjacent older strata, this explanation hardly seems necessary. It is true that undoubted glacial erratics exist in the Upper Marine strata of the Newcastle district, but they occur on what is probably a lower horizon. Above the conglomerates occur alternating beds of shale, sandstone, and conglomerate, the shales predominating as the top of the series is reached; here thin bands of dolomite and earthy limestone also occur.

The Upper Marine strata in these western districts are singularly poor in fossil remains, and such as do

occur are found in the lower beds only. The following forms have been identified:—

<i>Martiniopsis subradiata.</i>	<i>Conularia inornata.</i>
<i>Spirifer vespertilio.</i>	<i>Goniatites micromphalus.</i>
<i>Spirifer tasmaniensis.</i>	<i>Fenestella fossula.</i>
<i>Productus brachythærus.</i>	<i>Stenopora tasmaniensis.</i>
<i>Mæonia carinata.</i>	<i>Aviculopecten tenuicollis.</i>
<i>Strophalosia Clarkei.</i>	<i>Platyschisma.</i>

In some localities the basal conglomerates are auriferous; at Tallawang, and at Gough's Valley, near Gulgong, the auriferous conglomerates have been mined, and have yielded from 1 to 15 dwt. of gold per ton, while nuggets weighing up to 5 oz. have been obtained. The gold, which was coarse and water-worn, had undoubtedly been shed by reefs in the underlying Lower Palæozoic formations at the time the conglomerates were being formed, but its distribution in the conglomerates was very patchy.

The South-Western Coal-field.—The Upper Marine Series outcrops in the valleys intersecting the tableland in the neighbourhood of Bundanoon, &c., and consists mainly of sandstones and shales containing abundant marine fossils. Farther south at Tallong the formation, which ranges up to 400 feet in thickness, consists mainly of conglomerates with thin bands of fossiliferous sandstone. The pebbles in the basal conglomerates have been derived from the underlying older Palæozoic rocks, and include graphitic slates, quartzite, &c.

The Illawarra District.—Here, as has already been shown with regard to the Western Coal-field, the Lower Marine Series is absent and the Upper Marine Series, where the base is visible, rests unconformably upon truncated Lower Palæozoic strata. Near the southern edge of the Permo-Carboniferous basin, however, fresh-water beds, such as those at the Clyde River, underlie the Upper Marine Beds—but, as already pointed out, to a very limited extent. Upper Marine strata outcrop along the coast from Wollongong to as far south as Ulladulla. North of the Shoalhaven River they are overlain by the Upper Coal Measures, but south of it they occupy the surface of the tableland over a very considerable area. Where the tableland is intersected by the river valleys, these beds have been removed, and the underlying Lower Palæozoic strata exposed. The Upper Marine Beds, which here have a maximum thickness of about 3,000 feet, have been subdivided as follows:—

	Thick.
Volcanic Series—Crinoidal shales ..	1,000 feet
Nowra grits	250 ..
Wandra-Wandrian sandstone ..	550 ..
Conjola Beds	1,400 ..

(a) *Conjola Beds.*—These occur at the base of the series and rest either upon the underlying fresh-water beds, or unconformably upon Devonian or older strata. They consist of conglomerates, grits, and pebbly sandstones. Large boulders of granite, quartz porphyry, and quartzite occur both in the basal conglomerates and the overlying beds of coarse sandstone. Marine

SECTION FROM CLYDE GORGE THROUGH WANDRAWANDIAN BORE
TO JERVIS BAY BORE

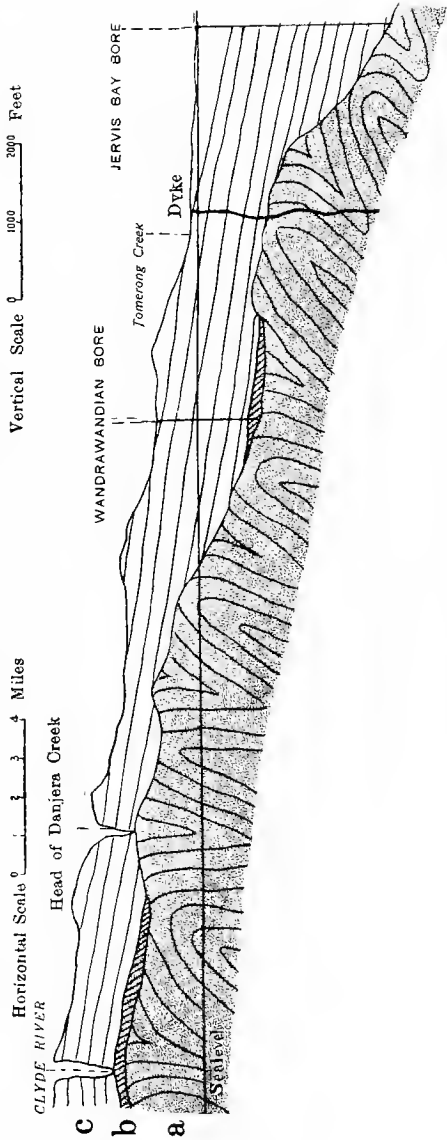


Fig. 43.

Section of Perno-Carboniferous and Devonian Strata, Clyde River.

A = Devonian Strata, B = Clyde River Coal-measures, C = Upper Marine Series.

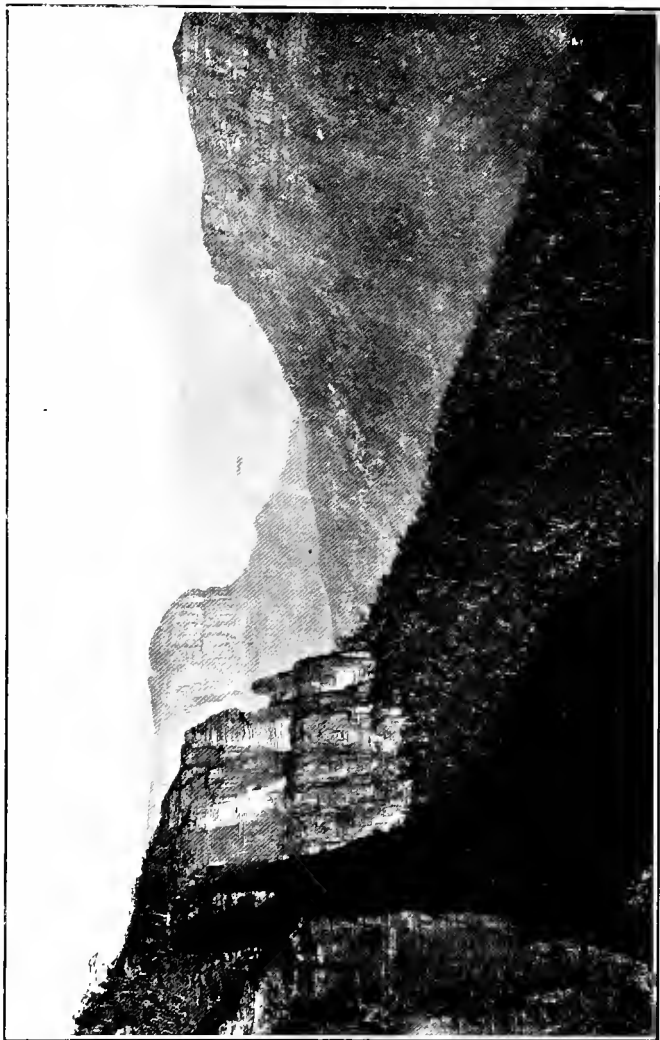


Fig. 44.

The Grose Valley, Blue Mountains, showing massive Triassic sandstones resting upon the Upper Coal Measures. The outcrops of the latter are covered with forest. The rounded hill in the distance is Mt. Hay, and is capped with Tertiary Basalt.

fossils are fairly common in these beds, particularly the genus *Maonia* (a pelecypod).

(b) *The Wandra-Wandrian Sandstones*.—These outcrop strongly along the road from Nowra to Milton, but possess no features of special interest.

(c) *The Nowra Grits*.—These are the gritty sandstones which outcrop around the township of Nowra and along the banks of the Shoalhaven River. They resemble the Muree rock of the Hunter River district both in lithological character and in their contained fossils.

(d) *Crinoidal Beds*.—These consist mainly of marine shales and sandstones. In the Kiama district their place is taken largely by the Volcanic Series. The lower beds contain crinoid stems in abundance, while in the Gerringong district the strata are literally crowded with fossils, due probably to the rapid killing off of the marine organisms by the showers of fragmental material which now began to be ejected by volcanoes. The richness of this marine fauna is shown in the following list of fossils:—

Upper Marine Fossils from Gerringong.

PLANTÆ.—Coniferous wood (*Dadoxylon*), Fucoid remains.

CRINOIDEA.—*Tibrachiocrinus corrugatus*, *Phialocrinus Stephensi*.

POLYZOA.—*Stenopora crinita*, *S. Tasmaniensis*, *Fenestella fossula*, *F. internata*, *Polypora*, *Protoclepora ampla*.

BRACHIOPODA.—*Lingula ovata*, *Productus brachythæus*, *Diclasma hastata*, *Martiniopsis subradiata*, *Martiniopsis oviformis*, *Spirifer vesperilio*, *S. Tasmaniensis*, *S. Clarkei*, *S. Strzeleckii*, *Spiriferina duodecimcostata*.

PELECYPODA.—*Deltopecten subquinguiliniatus*, *D. leniusculus*, *Merismoptera macroptera*, *Mæonia elongata*, *M. valida*, *M. carinata*, *Chænomya Etheridgei*, *C. Mitchellii*, *Astartila polita*, *Notomya securiformis*, *Stutchbarria costata*, *Nuculana Darwini*.

GASTEROPODA.—*Platyschisma oculum*, *Ptycomphalina Morrissiana*, *Mourlonia Strzeleckiana*, *Murchisonia verneuliana*.

PTEROPODA.—*Hyalithes lanceolata*, *Conularia inornata*.

CEPHALOPODA.—*Goniatites micromphalus*, *Orthoceras*.

(c) *The Volcanic Series*.—From the Cambewarra Mountains to Port Kembla the upper portion of the Upper Marine formation consists entirely of lavas and tuffs: these have in the neighbourhood of Kiama a maximum thickness of about 1,000 feet. To the north, south, and west the volcanic series gradually thins out and gives place to ordinary marine sediments. From the first centre of eruption, which seems to have been in the neighbourhood of Kiama, a great series of basic lavas and tuffs was ejected and deposited on the surrounding sea-bottom. A second centre of eruption then developed further to the south, in the direction of Cambewarra, which pro-

duced trachytic lavas and tuffs; these in turn were followed by basic lavas. Vulcanicity was resumed on a smaller scale in the Upper Coal Measures epoch with a further outpouring of basic lavas. The section in Fig. 45 shows this volcanic series, including the lavas of the coal-measures.

The whole series of volcanic rocks, although it varies from basic to intermediate in composition, is closely related from a chemical point of view, all the flows having been derived from a common magma. From a petrological standpoint they have all been grouped together by Mr. G. W. Card under the name of Latite.

1. *Westley Park Tuffs*.—These are about 40 feet in thickness; followed downwards, they merge imperceptibly into marine shales and sandstones. They contain abundant marine fossils, while ejected volcanic blocks up to a ton or more in weight are not uncommon.

2. *Blowhole Flow*.—This outcrops at sea-level at Kiama, and extends southwards as far as Gerringong. This flow is a typical basalt in appearance, and is about 140 feet in thickness.

3. *Kiama Tuffs*.—These overlie the Blowhole flow, and have a thickness of 120 feet. They are basic in composition, fine-grained and well stratified. Bands of lapilli occur at intervals. Their basic composition results in a rich reddish-brown colour on weathering.

4. *Bumbo Flow*.—This is a very extensive sheet of lava, and ranges from 30 to 500 feet in thickness. It is strikingly columnar, some of the columns attaining a height of 50 or 60 feet and a diameter of 8 feet.

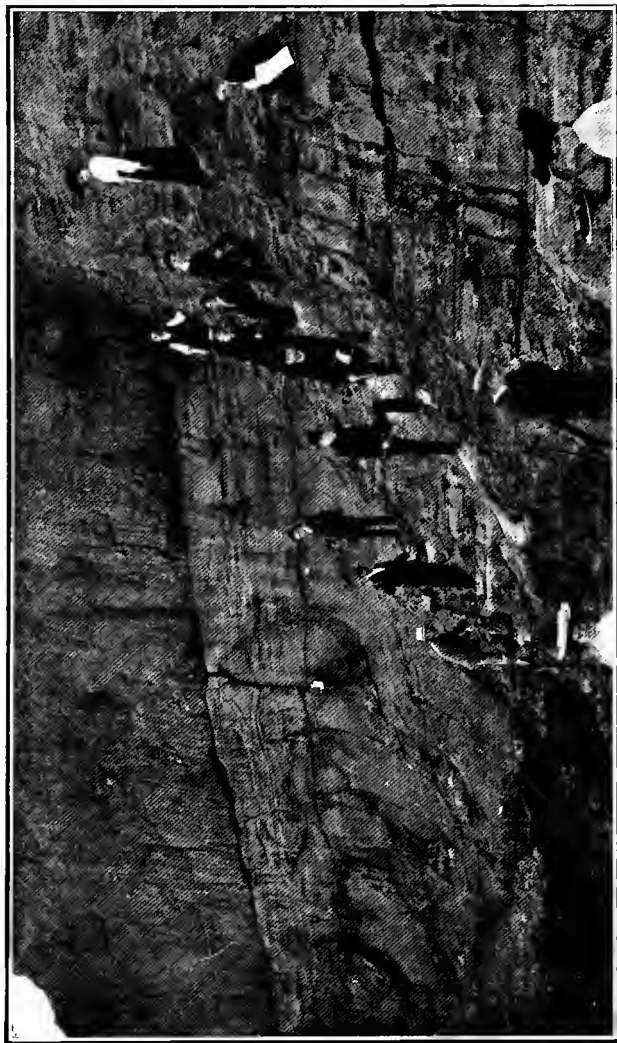


Fig. 46.

Basalt Flow resting upon Fossiliferous Marine Tuffs at Westley Park, South of Kiama.

The rock varies from basic to intermediate in composition and is markedly porphyritic in texture, the phenocrysts of Labradorite being as much as $1\frac{1}{2}$ inches in length. The rock also contains a very small percentage of native copper. The flow has been extensively quarried in the neighbourhood of Kiama for railway ballast and for road-making, its perfect columnar structure being of material assistance in quarrying.

5. *Jamberoo Tuffs*.—These are trachytic in composition, and have a maximum thickness of over 600 feet. They extend from Cambewarra as far north as Jamberoo, and overlap the basic flows and tuffs already described.

6. *Saddleback-Dapto Flow*.—This is a basalt, and extends from Saddleback Mountain northwards to Dapto; it has a thickness of 60 feet and upwards.

7. *Cambewarra Flow*.—Excepting perhaps the Bumbo flow, this is the largest and most extensive flow in the district. It has a maximum thickness of 600 feet, and extends from Stockyard Mountain (north-west of Kiama) to the southern edge of the Cambewarra Range, a total distance of 22 miles. It much resembles trachyte, and consists mainly of Orthoclase and Plagioclase, with a subordinate amount of Augite. The chemical analyses of these lavas are given on page 247. They are all somewhat rich in potash, and while they closely resemble basalts and trachyte in land specimens, they belong more correctly to the group of latites.

An interesting trachyte boulder bed occurs at the top of the Upper Marine Series in this district, extending from Cambewarra nearly to Wollongong. The boulders are composed of a rock identical with the Cambewarra trachyte, and gradually diminish in size as the bed is traced northward. Its position in the succession is shown in Fig. 53.

The Bong-Bong basalt and the Kangaroo Mountain basalt shown in the section in Fig. 45 are now considered to be intrusive sills.

(D).—THE TOMAGO SERIES AND THE DEMPSEY SERIES.

The Middle Coal Measures.

Lying between the Upper Marine Series and the Upper Coal Measures in the Newcastle-Maitland area of the Hunter River district there is a considerable thickness of fresh-water beds. The lower part of this formation contains several workable coal seams, and has been called the Tomago or East Maitland Coal Measures.

(a) *The Tomago or East Maitland Coal Measures.*—These are fresh-water beds, varying from 600 to 2,000 feet in thickness, and include the following strata:—

Four-mile Creek beds—	feet
Conglomerates	20
Sandstones and shales	58
No. 1 Coal Seam (top seam)	4½
Sandstones	68
No. 2 Coal Seam	7
Shales (with <i>Glossopteris</i>)	5

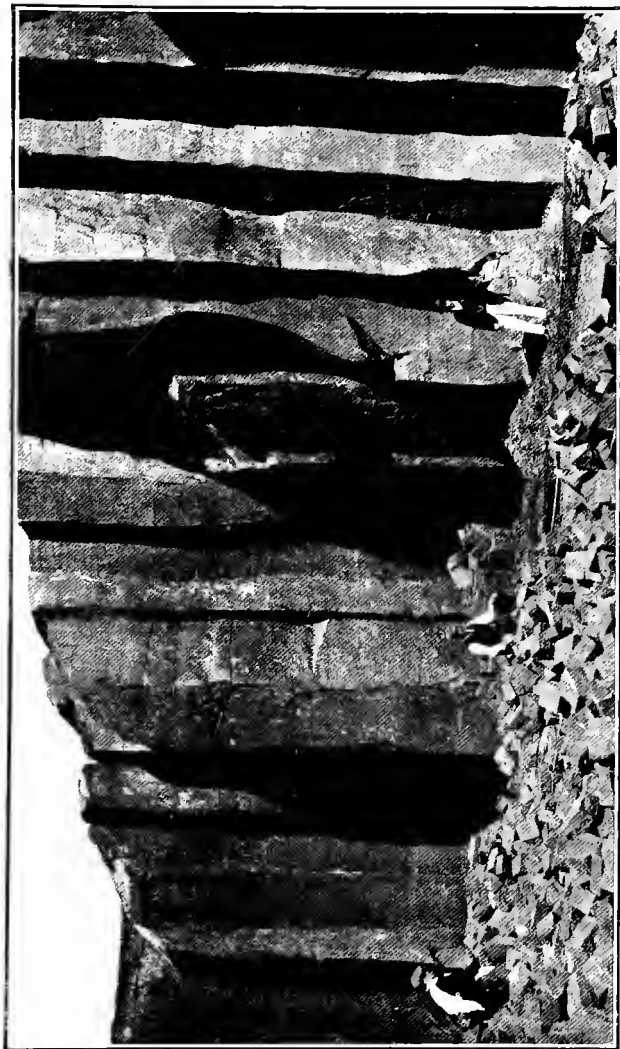


Fig. 47.

Columnar Basalt (Bumilo Flow), Kiama.

No. 3 Coal Seam	6
Shales and sandstones (with two thin coal seams)	38
Buttai beds—	
Sandstones and shales	220
Rathluba beds—	
Rathluba Coal Seam	11
Shales, &c.	82
Morpeth Coal Seam	4½–8
Shales, sandstones, &c.	94

The coal-seams are very variable in thickness, frequently splitting, and in places show marked evidence of contemporaneous erosion. The coal is friable and inferior to that obtained from the Lower and Upper Coal Measures. The aggregate thickness of coal is about 40 feet, of which about 20 feet has been proved to be workable.

(*b*) *The Dempsey Series*.—This is a series of fresh-water beds, shales, and sandstones, about 2,000 feet in thickness, lying between the East Maitland Coal Measures and the Upper or Newcastle Coal Measures. They appear to contain no coal-seams, and possess no features of special interest.

(E).—UPPER COAL MEASURES.

This, the topmost subdivision of the Permo-Carboniferous system, extends over nearly the same area as the Upper Marine Series, and, except in parts of the Hunter River district, directly succeeds the

latter formation. It is the most important and extensive coal-bearing formation in Australia. The Upper Coal Measures in the Newcastle district include the following strata:—

	feet
Wallarrah coal seam	5
Shales	6
Conglomerates	120
Great Northern coal seam	14
Tuffaceous shales (with fossil trees) ..	80
Conglomerates	45
Shales, sandstones, and cherts	54
Upper Pilot coal seam	8
Shales, tuffs, and cherts	33
Lower Pilot coal seam	5
Conglomerates with current bedding ..	200
Cardiff coal seam (with bands)	16½
Shales, &c.	30
Burwood coal seam	13½
Shales and cherts	65
Nobby's coal seam	6
Shales	40
Dirty coal seam	7
Shales	50
Yard coal seam	3
Shale and sandstones	200
Borehole coal seam	6-20
Waratah coal seam	30
Shales, &c. (with two small coal seams)	170
<hr/>	
Total thickness	1,221

It will be seen that the Newcastle Coal Measures include ten important coal seams, as well as several smaller ones. Of these, the Borehole seam has received the greatest attention from the coal-miner, and is worked at nineteen distinct collieries. It varies from $4\frac{1}{2}$ to 20 feet in thickness, and in places splits into two seams, the upper division being then known as the Young Wallsend Seam. The upper seams correspond with those in the Illawarra Coal Measures, and are being worked in several collieries. The two Pilot seams apparently coalesce in a south-westerly direction, and form the Australasian Seam, which (including clay bands) has a thickness of 50 feet, and is the thickest coal seam in New South Wales; only the lower 7 feet of the coal is mined.

The aggregate thickness of workable coal in the seams of the Newcastle Coal Measures is from 35 to 40 feet.

The coals are fairly hard; they include both splint and bituminous coals, and the quality is excellent for gas-making and steaming purposes. The strata with which these coal-seams are associated consist of conglomerates, sandstones, shales, and cherty tuffs. Conglomerates are strongly in evidence in the upper part of the series, individual beds ranging up to 200 feet in thickness. A feature of special interest with regard to these conglomerates is that they show strongly marked current bedding, the laminae in many cases dipping from the ocean towards the land; this would seem to indicate that the land which supplied the pebbles for the building up of these beds lay to the

30 feet Greenish grey shales passing into red shales like the chocolate shales of the Narrabeen stage.

10 feet Conglomerate weathering ochreous brown.

10 feet Chiefly shales, greenish-grey to ochreous and red.

2 feet Hard whitish sandstone. The basal bed of the Triassic rocks.

2 feet Coal much weathered. **This is the Wallarah or Bulli seam**

1 inch Brown shale, with *Furcibaria*.

1 inch Coal.

8 inch Shaly coal, with laminae of brown shale.

3 feet Dark grey shale, becoming lighter in colour downwards.

1 foot Red shale like chocolate shale.

1 foot Fine-grained sandstone.

45 feet Coarse conglomerate.

20 feet Conglomeratic sandstone.

55 feet Coarse Conglomerate.

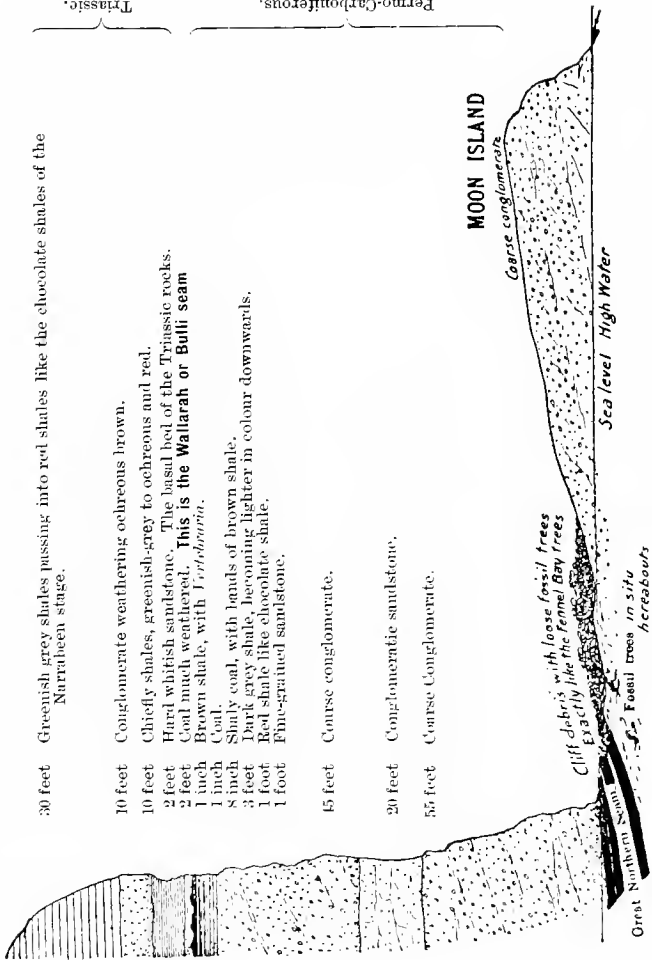


Fig. 48.

Cliff Section, Moon Island, south of Newcastle, showing junction of Triassic Rocks and Upper Coal-measures. (David.)

east of the existing coast. The shales contain an abundance of fossil plants, among which the genus *Glossopteris* is particularly plentiful. Remains of fossil insects (Mayflies) also occur on some horizons. The beds of chert which occur at frequent intervals, particularly between the Nobby's and Burwood coal-seams, have been shown to consist of minute broken fragments of felspar crystals, interspersed with volcanic ash. These beds then, fine-grained as they are, are really tuffs; excellent samples of them may be seen in the cliff sections adjacent to Newcastle.

Origin of the Coal.—Professor David, in his description of the Pilot seam and the adjacent strata, makes the following remarks regarding the origin of the coal:—“No more impressive evidence can be imagined as to the origin *in situ* of our coal seams than that afforded by this beautiful section. (See Fig. 49). The beds of chert which separate the Upper Pilot seam from the Lower are traversed by numerous vertical stems of large trees, now converted into chalcedony. These can be traced downwards almost from the floor of the Upper seam through a thickness of from 20 to 30 feet of chert into the roof of the Lower seam. As they are traced downwards into the top layer of the coal of the Lower Pilot seam, the substance of the fossil trees changes quickly from chalcedonic quartz into a form of hydrocarbon. It is a fact most obvious, even to the most casual observer, that these trees are all *in situ* in the roof of this lower coal-seam, and that their stems and roots have become partly absorbed into the substance of the coal. The

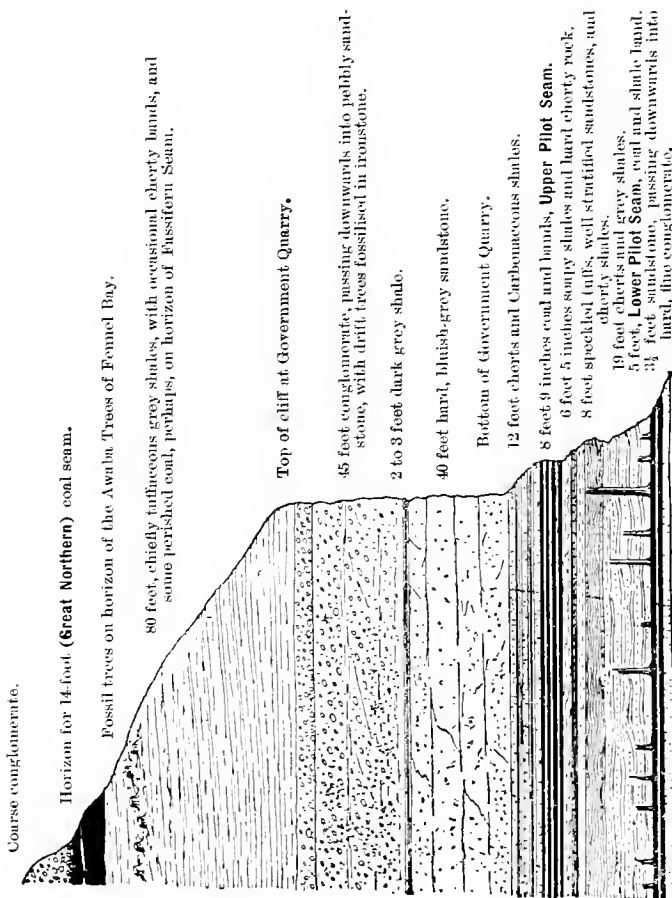


Fig. 49.

Section of Upper Coal Measures, Government Quarry, Swansea. (David.)

trees were about 5 yards apart from centre to centre, and their diameter varies from 10 to 15 inches. In the floor of both the Upper and Lower Pilot seams,

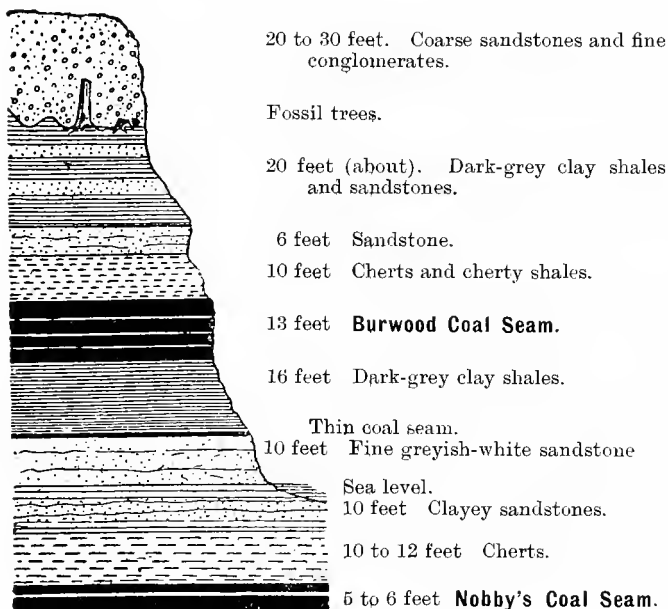


Fig. 50.

Cliff Section, Portion 30, Parish of Kahibah. south of Newcastle (David). This, with the two preceding sections, gives a nearly complete succession of the Upper Coal-measures as seen outcropping along the coast south from Newcastle.

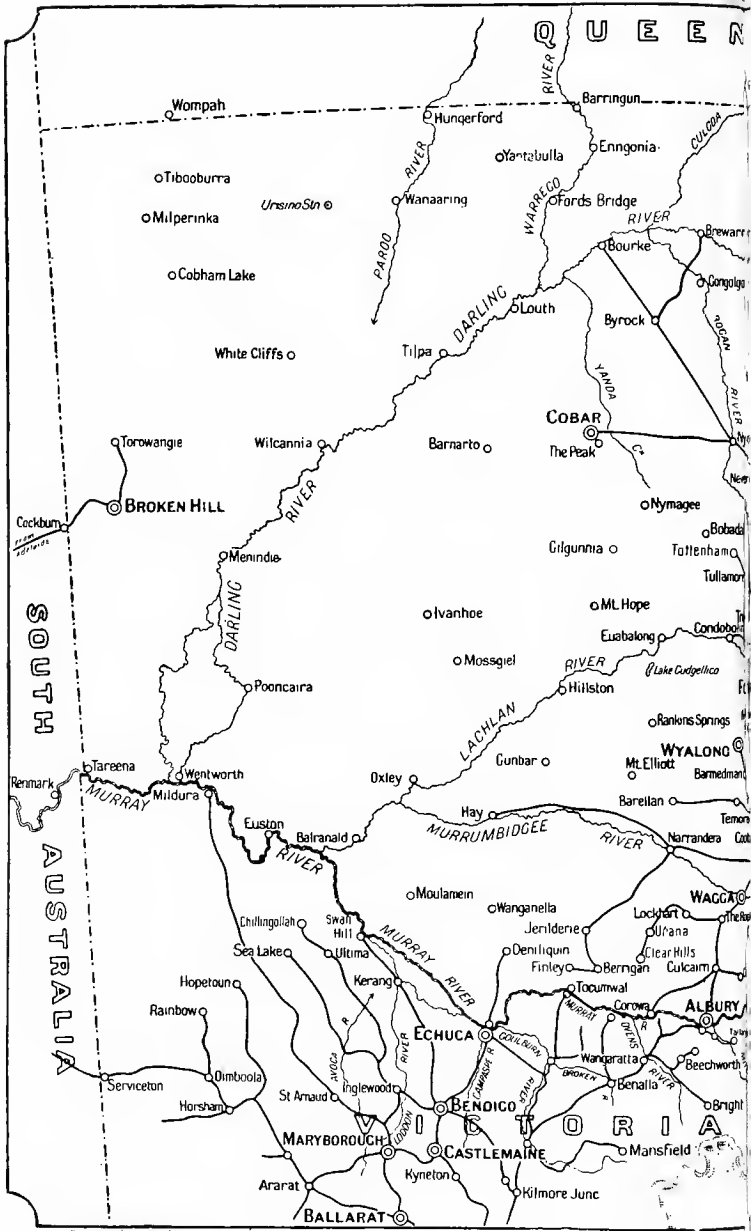
there are great numbers of more or less vertical roots of *Vertebraria* [the rhizome of *Glossopteris*, C.A.S.], while the layers of black shale between the beds of coal abound in *Glossopteris* [a fossil fern, C.A.S.], and the

black fireclay bands are full of mother-of-coal and sporangia [seed vessels]. It is quite evident that we have here to deal with an ancient fossil forest which marked the final stages in the evolution of a huge peaty swamp in Permo-Carboniferous times. This forest was formed of closely-packed, tall, coniferous trees, rooted on the surface of thick peat. It is clear, then, that in this seam, as in the case of all Newcastle seams, the woody material which went to form the coal actually grew on the spot where the seams are now found.

The past geological history of this part of the coal-field may probably be read as follows:—Along a wide coastal plain there was a development of plant growth in shallow marshes, the predominant type of plants at first being *Glossopteris* and *Sphenopteris*. This growth of lowly-organised plants like ferns was followed later by a spread of forest trees.

Rix's Creek Coal-field.—The Upper Coal Measures which occur at Rix's Creek, near Singleton, have a thickness of upwards of 1,000 feet and dip to the west. Bores put down in these measures at Ravensworth penetrated twelve (12) seams of coal, the aggregate thickness of coal being 86 feet. These coal measures are probably the equivalent of the Newcastle Coal Measures.

The Curlewis-Gunnedah Coal-field.—The same coal-seams extend in a westerly direction to Gunnedah, where they have been worked to a small extent. The



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Fig. 51.— Map of New South Wales, showing approximate area of



erred by the Upper Marine Sea & the Upper Coal Measure Swamps.

following succession of strata have been described from this locality by Mr. J. E. Carne.

		Thickness.
		feet.
Tertiary (?)	Dolerite Flow	200
	{ Hawkesbury Stage	130
Triassic ...	{ Narrabeen Stage { Chocolate shales	3
	{ Sandstones	40
	{ Conglomerates	90
	{ Sandstones	50
	{ Coal seam	12-15
	{ Shales, sandstones, and conglomerates... ..	100
Premo-Carboniferous—Upper	{ Coal seam	5
Coal Measures.	{ Cherty shales	50
	{ Sandstone, conglomerate, and shales	58
	{ Coal seam	6
	{ Shales and sandstone (unknown thickness) ... ..	...

The Murrurundi District.—Here the Upper Coal Measures Series consists mainly of lavas and tuffs; interstratified with them, however, there are some fresh-water beds.

The rhyolites and rhyolite tuffs which occur at the base of the series are probably of Carboniferous age, The fresh-water beds are about 100 feet thick, and contain at least one coal seam in which an important deposit of kerosene shale occurs, which is now being opened up. The lavas and tuffs associated with these fresh-water beds are basic in composition, and are upwards of 1,200 feet in thickness.

The Western Coal-field.—This coal-field occurs along the western edge of the Permo-Carboniferous

Basin, the coal measures outcropping beneath the Triassic strata along the sides of the valleys on the western edge of the Blue Mountains Tableland, from Lithgow northwards to Gunnedah. South from Lithgow the outcropping edge of the coal-basin trends south-west past Burraborang to the south-western coal-field.

The Lithgow Coal Measures are the equivalent of the Newcastle and Bulli Coal Measures, and in the Lithgow district have a thickness of about 480 feet; northwards the thickness gradually increases, until at Talbragar, and in the north-western coal-field generally, a thickness of about 1,200 feet is reached. The base of the coal measures in the Lithgow district is marked by a bed of conglomerate about 50 feet in thickness called the Marangaroo Conglomerate; the remaining strata consist of shales and sandstones, with a few thin bands of conglomerate and cherty tuffs. Seven coal seams are known to occur, three of which are of commercial importance. Of these the lowest (Lithgow seam) is the one most extensively worked, seven collieries operating on it at Lithgow, and five collieries at Wallerawang and Cullen Bullen.

The next seam is called the Upper Irondale Seam (sixth seam), and is 60-80 feet above the Lithgow seam. It is worked to some extent at Portland, Cullen Bullen, and Wallerawang, and is from 5 to 8 feet thick. The "Top" or "Katoomba" seam occurs at the top of the series, immediately below the Triassic strata. This seam is apparently identical

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with the "Bulli" seam of the Illawarra district and with the seam now being worked in the Balmain Colliery (Sydney). It has been mined for coal at Hartley Vale and elsewhere, but its importance is due mainly to the occurrence in it of a band of kerosene shale, varying from 2 feet to 6 feet in thickness, which has been extensively mined at Hartley Vale, Katoomba, &c. The nature and origin of kerosene shale will be referred to later. The shales associated with the coal-measures are very suitable for the manufacture of bricks, pottery, stoneware, and fire-bricks, and are being extensively used for this purpose at Lithgow. The fossil flora preserved in these shales is similar to that found in the corresponding strata in other districts, and includes *Glossopteris*, *Vertebraria*, *Sphenopteris*, *Phyllothea*, *Brachyphyllum*, *Dadoxylon*, and the *Naggerathiopsis*. In the cherty tuffs, near Lithgow, these plants are particularly well preserved.

The South-Western Coal-field.—This occurs adjacent to the Main Southern Railway Line from Mittagong to Tallong. Here the main streams have cut down their gorges through the Triassic strata which forms the surface of the Tableland, and have exposed the underlying upper coal-measures. These range up to 200 feet in thickness and include several coal seams. At Tallong, on the southern edge of the basin, conglomerate and sandstones predominate. Here the coal is of a very poor quality, as might have been expected, since it was produced at the very border of the coal swamps, and was therefore subject to

contamination by mechanical sediments. Here also the leaves of *Næggerathiopsis* are far more plentiful than fronds of *Glossopteris*, probably due to the fact that the dry land to the south and west was clothed with *Dadoxylon* trees from which the leaves were shed. Throughout this coalfield the coal is apparently not of such good quality as that from other parts of the State, owing to the relatively higher percentage of ash contained. Kerosene shale of very good quality has been mined near Mittagong.

The Southern (Illawarra) Coal-field.—The Upper Coal Measures in the Newcastle district dip south, and at Sydney are nearly 3,000 feet below sea-level. From here they begin to rise, until at Clifton they again appear above sea-level. Followed still further southwards, the strata continue to rise until, at Cambe warra on the southern edge of the basin, they reach an altitude of 1,600 feet. Here they have a thickness of only 40 feet, whereas, at Jamberoo, some 20 miles northwards, the thickness has increased to 850 feet, which is about the average thickness for the district. The strata, often referred to as the Bulli Coal Measures, consist mainly of shales and sandstones (see Fig. 53), but at Jamberoo the basal beds are tuffs, and two basaltic lava-flows occur in the series. Cherty tuffs, similar to those of the Newcastle district, also occur. A section of the Upper Coal Measures in the neighbourhood of Unanderra and Mount Kembla is given in Fig. 53. It will be seen that these contemporaneous lava-flows are included. Seven seams

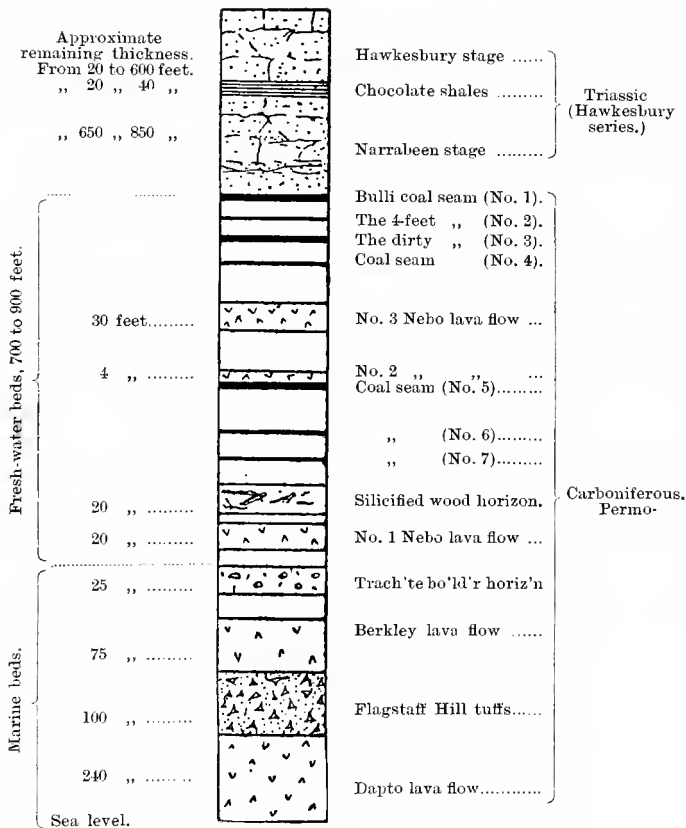


Fig. 53.

Vertical succession of Triassic and Permo-Carboniferous Strata, Wollongong District. (Harper.)

of coal exist in the Illawarra district, of which the following are the most important:—

- | | | |
|---------------------------------|----------|-----------------|
| 1. The Bulli Seam | .. .. | 2-11 feet thick |
| 2. The Four-feet Seam | .. .. | 4 |
| 3. The Thick Seam or Dirty Seam | .. .. .. | 16-26 |
| 4. The Eight-feet Seam | .. .. | 7-9 |
| 5. The Bottom Seam | .. .. | 6 |

Of these, the top, or Bulli seam, has been mined all along its outcrop from Clifton to Mount Kembla. The coal is an excellent steaming and coking coal.

The same seam is being mined at Helensburgh in the Metropolitan Colliery, at a depth of 1,100 feet below the surface, and in the Sydney Harbour Colliery, at a depth of about 2,900 feet below sea-level. The coal from the latter colliery is semi-anthracitic in composition, and is almost smokeless.

CHAPTER X.

PERMO-CARBONIFEROUS PERIOD (*continued*).

I.—PERMO-CARBONIFEROUS LIFE.

(a) *The Marine Fauna*.—The marine life of this period is thoroughly Palæozoic in character, and contains an admixture of what would, in the Northern Hemisphere, be considered as distinct Carboniferous and Permian types. That it differs markedly from the marine fauna of the true Carboniferous formations of New South Wales, already described, is shown by the following list of its more important members; such genera as are common to the two periods are represented, in most cases, by different species:—

Foraminifera:—*Nubecularia*, *Lituola*, *Nodosaria*,
Endothyra, *Lagena*.

Spongida:—*Hyalostelia*.

Actinozoa:—*Zaphrentis*, *Trachypora*.

Crinoidea:—*Phialocrinus*, *Tribrachiocrinus*.

Asteroidea:—*Palæaster*.

Echinoidea:—*Archæocidaris*.

Polyzoa:—*Fenestella*, *Polypora*, *Protoretetpora*,
Stenopora.

Brachiopoda:—*Lingula*, *Dielasma*, *Productus*,
Martiniopsis, *Spirifer*, *Spiriferina*, *Strophalosia*.

Pelecypoda:—*Aviculopecten*, *Deltopecten*, *Mæonia*,
Merismoptera, *Chænomya*, *Cleobis*, *Notomya*,
Edmondia, *Eurydesma*, *Stutchburia*, *Pleuro-*
phorus, *Astartila*, *Aphanaia*.

Pteropoda:—*Hyolithes*, *Conularia*.

Gasteropoda:—*Keeneia*, *Platyschisma*, *Ptycomphali-*
na, *Mourlonia*, *Murchisonia*.

Cephalopoda:—*Orthoceras*, *Goniatites*.

Crustacea (Ostracoda):—*Entomis*, *Polycope*, *Car-*
bonicola.

PROTOZOA.—Foraminifera are abundant, particu-
 larly so in the lower marine strata of the Pokolbin
 district. Radiolaria are not known to occur.

SPONGIDA.—Sponges are uncommon.

CŒLELENTERATA.—The corals are the only group
 represented, and are uncommon, only two genera
 being known. The refrigeration of the climate, as
 indicated by the glacial beds, is the cause generally
 assigned for the practical extinction of the more abun-
 dant corals of the previous periods.

ECHINODERMATA.—The crinoids were at times abun-
 dant, particularly in the latter part of the Upper
 Marine Epoch. The genus *Phialocrinus* had a calyx
 up to 4 inches in diameter, and is the largest known
 crinoid yet found in Australia. *Tribrachiocrinus* is
 an interesting type, possessing three simple arms and
 two double-arms—it is the commonest genus, and is
 confined to Australia. Large starfish occur, particu-
 larly on the Ravensfield sandstone horizon. Sea-
 urchins were not numerous, while cystoids and blas-
 toids are unknown.

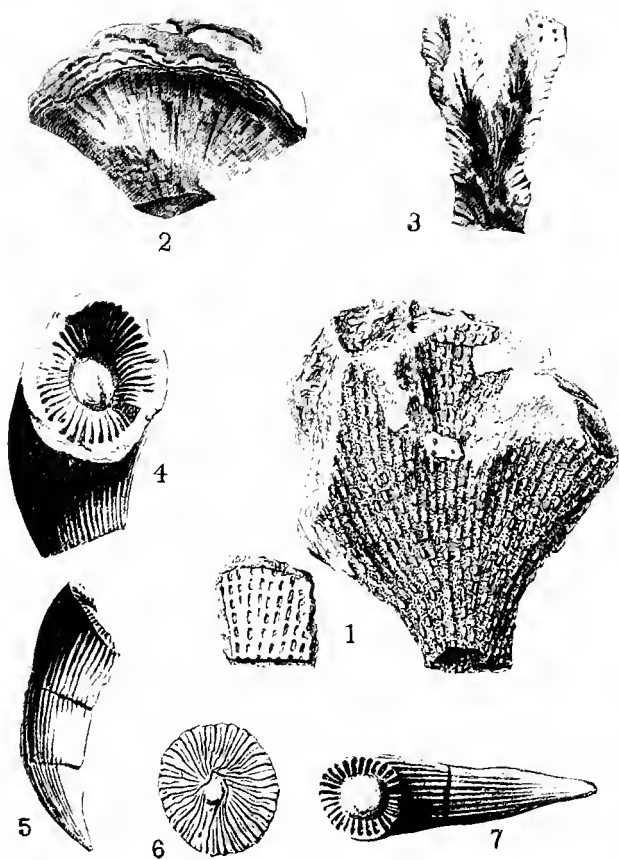


Fig. 54.

Permian-Carboniferous Corals and Polyzoa.

1. *Polypora*. 2. *Stenopora crinita*. 3. *Trachypora Wilkinsoni*.
 4. *Zaphrentis Cainoloni*. 5-7. *Zaphrentis Greyfriana*.

MOLLUSCOIDEA.—The Polyzoa were more abundant than they had ever been before. The Fenestellidæ (*Fenestella*, *Polypora*, &c.) occurred in great numbers, and their beautiful lace-like structures are wonderfully well preserved in some of the marine shales. The coral-like genus *Stenopora* was also abundant, and is represented by both massive (*S. crinita*) and branching forms (*S. Tasmaniensis*).

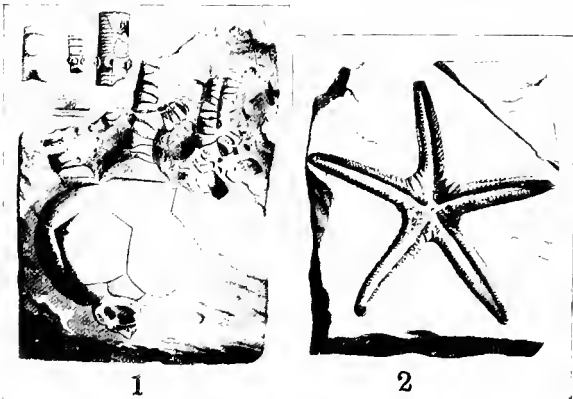


Fig. 55.

Permo-Carboniferous Echinodermata.

1. *Phialocrinus princeps*. 2. *Paleaster giganteus*.

The BRACHIOPODA lived in countless numbers, and probably dominated all the other invertebrates. The Spiriferidæ (*Spirifer*, *Martiniopsis*, &c.) and the Productidæ (*Productus* and *Strophalosia*) were the most abundant of these; the genus *Spirifer*, in particular, was represented by large numbers, both of species and individuals. *Martiniopsis* supplied the largest

brachiopod shells yet found in Australia. The Strophomenidæ and Orthidæ, so abundant in the Carboniferous strata, are absent here.

MOLLUSCA.—These rival the Molluscoidea in numbers, the two sub-kingdoms together providing the great bulk of the marine fauna. The Permo-Carboniferous was undoubtedly the "Age of the Shell-fish." The Pelecypods dominate the other classes of the mollusca, and were more abundant and individually larger than they had been in any previous period. The shells of *Aphanaia* attained a length of 15 inches, while *Cleobis* and *Eurydesma* also built very large and thick shells.

The Gasteropoda, while not so numerous as the Pelecypoda, were larger than they had ever been before. *Platyschisma*, and its ally *Keceneia*, were the largest and most characteristic genera. The Cephalopods were relatively uncommon; *Orthoceras* still persists, and, together with *Goniatites*, is fairly abundant on the Ravensfield sandstone horizon. The great advance in the Cephalopods, which took place in other parts of the world towards the close of the Palæozoic Era, and which foreshadowed their extraordinary development in the Mesozoic Era, has no parallel in New South Wales.

ARTHROPODA.—Trilobites are unknown, and evidently became extinct at the close of the Carboniferous Period.

The Ostracods are the only known representative of the sub-kingdom, and even those are not abundant.

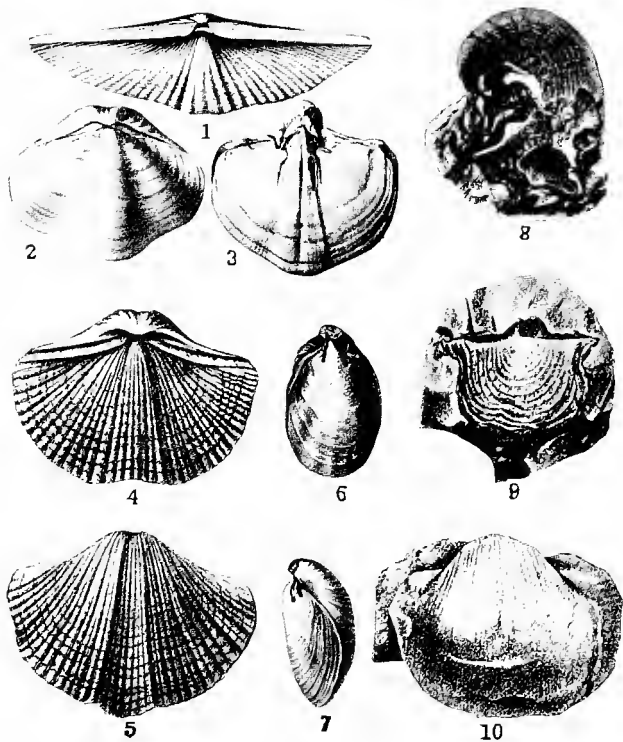


Fig. 56.

Permo-Carboniferous Brachiopods.

1. *Spirifer vesperilin*. 2. *Martiniopsis subradiatus* 3. *Martiniopsis subradiatus* (internal cast). 4-5. *Spirifer Tasmanianus*. 6-7. *Terebratula (Dichasma) saevulus*. 8, 10. *Productus brachytherus* (ventral valve). 9. *Productus brachytherus* (dorsal valve).

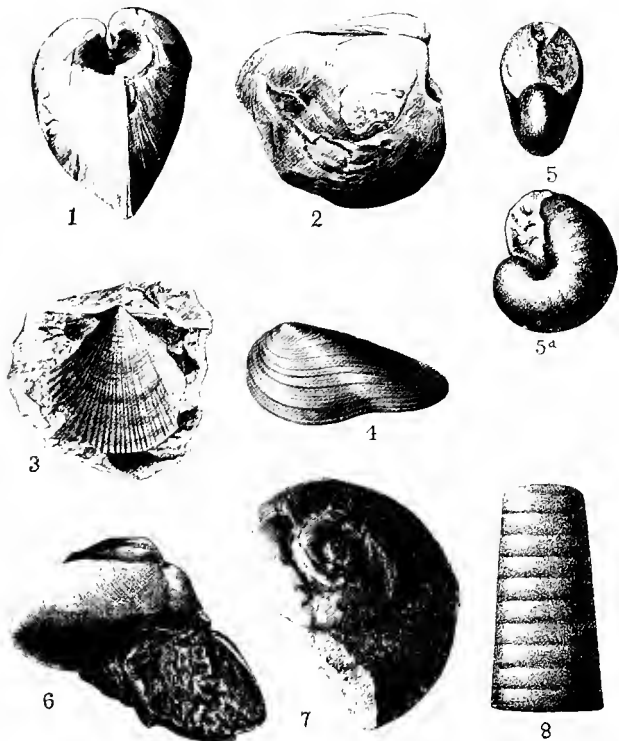


Fig. 57.

Permo-Carboniferous Mollusca.

1-2, *Encyclusma cardatum* (Morris). 3, *Arivalopecten tenuicollis* (Dana).
 4, *Micaia elongata* (Dana). 5, *Goniatites (Lythicerus) mirroniphalus*
 (Morris). 6, *Keocia platyschismoides* (Eth. fil.) 7, *Platyschisma oculum*
 (Sowerby). 8, *Orthoceras (Cameroceras) Phillipsi* (De Kon.)

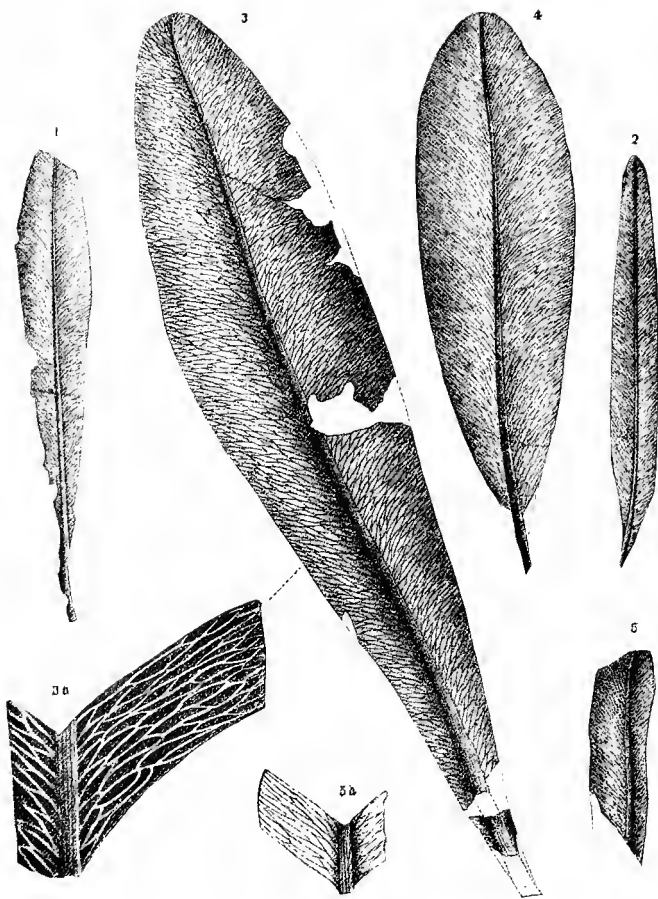


Fig. 58.

Permo-Carboniferous Plants.

1-2. *Glossopteris linearis* (McCoy). 3-4. *Glossopteris Browniana* (Bgt.).

(B.) *The Terrestrial Flora and Fauna.*—This includes the following genera:—

Equisetales.—*Phyllothea*, *Schizoneura*, *Annularia*.

Filicales (Ferns)—*Glossopteris*, *Gangamopteris*,
Vertebraria, *Sphenopteris*, *Alethopteris*, *Taeniopteris*.

Cordaiteæ (?)—*Dadoxylon*, *Næggerathiopsis*.

Coniferæ (?)—*Brachyphyllum*.

Ginkgoaceæ—*Baiera*.

Insecta—*Neuroptera* (?).

Amphibia—*Bothriceps*.

Pisces (Fish)—*Urostheneis*.

The most characteristic member of this flora is the fern *Glossopteris* (Fig. 58); its fronds occur in enormous numbers, and the peculiar anastomising venation shown in the illustration is very characteristic. *Gangamopteris*, although less abundant, is just as characteristic, particularly for the earlier part of the period; its venation is like that of *Glossopteris*, but has no midrib (Fig. 59). *Vertebraria* was the rhizome of *Glossopteris*. Both ferns must have flourished abundantly in the coal-measure swamps, as also did the horsetail *Phyllothea*. *Dadoxylon* was the largest of the plants, and probably ranged up to 100 feet in height; numerous trunks occur *in situ* immediately on top of some of the coal-seams, and it is frequently found as driftwood, both in the marine and fresh-water beds. It apparently flourished on the dry land surrounding the coal swamps, and spread over the surface of the coal-seams after coal-making conditions

had ceased. The fossil leaves called *Neggerathiopsis* are believed to have been the foliage of these trees.

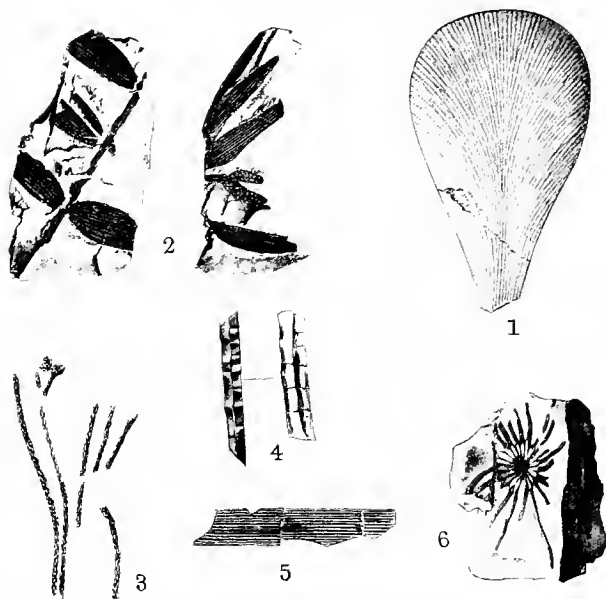


Fig. 59.

Permo-Carboniferous Plants.

1. *Gangamopteris Clarkei* (Feist.).
2. *Schizoneura australis* (Eth. fils.).
3. *Brachyphyllum australe* (Feist.).
4. *Vertebraria australis* (McCoy).
5. *Phyllothea australis*—stem (Bgt.).
6. *Phyllothea australis*—whorl of leaves.

The classification of *Dadoxylon* is uncertain, but it is believed to have belonged to the *Cordaites*, a group which combined some of the features of Conifers and Cycads, and was, perhaps, the ancestor of both. *Schizoneura*, *Alethopteris*, *Tacniopteris*, and *Baicra* appear only towards the close of the period; in the

Balmain Colliery they occur immediately above the coal seam, and are associated there with *Glossopteris*; all four plants, as well as *Phyllothecca*, pass up into the overlying Triassic strata. *Sphenopteris* also occurs in both formations, but is represented by different species.

It will be of interest to make a comparison here of the Carboniferous, Permo-Carboniferous, and Triassic floras.

The following table gives a list of the more important members of the flora from each of these periods:—

	Carboniferous.	Permo-Carboniferous.	Triassic.
Equisetales	<i>Calamites</i>	<i>Phyllothecca</i> <i>Schizoneura</i> <i>Australis</i>	<i>Phyllothecca</i> <i>S. Australis</i>
Lycopodiales	<i>Lepidodendron</i>	<i>Annularia</i> (Unknown)	<i>Equisetum</i> (Unknown)
Filicales	<i>Aneimites</i> <i>Rhacopteris</i> <i>Cardiopteris</i> <i>Archæopteris</i>	<i>Glossopteris</i> <i>Gangamopteris</i> <i>Vertebraria</i> <i>Alethopteris</i> c.f. <i>Australis</i>	<i>Thinnfeldia</i> <i>Teniopteris</i> <i>Macrotaeniopteris</i> <i>Alethopteris</i> <i>Australis</i>
Cordaiteæ	(?)	<i>Sphenopteris</i> <i>Dudoxylon</i>	<i>Sphenopteris</i> (Unknown)
Coniferæ	(Unknown)	<i>Brachyphyllum</i>	(?)
Cycadales	(Unknown)	(Unknown)	<i>Podozamites</i> <i>Pterophyllum</i>
Ginkgoaceæ	(Unknown)	<i>Baiera</i>	<i>Baiera</i> <i>Ginkgo</i>

It will be seen that not a single member of the Carboniferous flora passed upwards into the Permo-Carboniferous. The refrigeration of the climate which took place at the beginning of the latter period, as indicated by the glacial beds in New South Wales

and other parts of Australia, has been suggested as the cause of this marked break between the two floras. There is also a very marked difference between the Permo-Carboniferous and Triassic floras, all the more important members of the former failing to pass the boundary. Some few members of the Triassic flora (*Schizoneura*, *Alcthopteris*, *Tacniopteris*, and *Baiera*) appeared, however, before the close of the Permo-Carboniferous, and we have thus a slight commingling of the two floras in the topmost beds of the Upper Coal Measures.

The Permo-Carboniferous flora, although so different from that of the Triassic Period, has, as a whole, a decidedly Mesozoic aspect, and, were it not for the fact that some of the fresh-water beds containing these fossil plants are actually interstratified with marine strata containing an undoubted Upper Palæozoic fauna, the strata containing the *Glossopteris* flora would probably have been referred to the Mesozoic Era.

Land Animals.—The terrestrial fauna is a very limited one: a Labyrinthodont (*Bothriiceps major*) has been obtained from the Upper Coal Measures at Airly in the Lithgow district, and is the oldest vertebrate animal, other than fish, yet found in New South Wales. A fossil fish (*Urosthencus Australis*) has been obtained from the Upper Coal Measures, both in the Lithgow and Newcastle districts, while from the latter locality the wings of some undescribed insects, belonging probably to the Neuroptera, have been obtained.

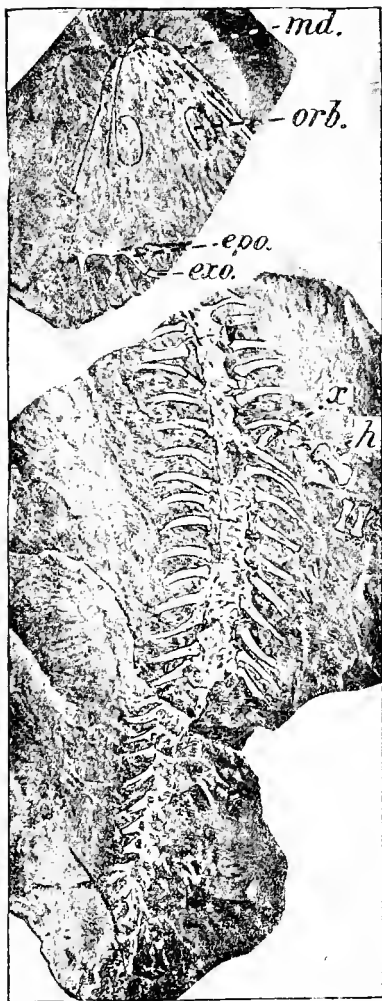


Fig. 60.

Permo-Carboniferous Amphibian—*Bothriiceps major* (A.S.W.)—from Airley.

II.—ECONOMIC IMPORTANCE OF THE PERMO-CARBONIFEROUS FORMATION.

The Coal—Quality and Available Supply.—Various estimates have been made from time to time as to the quantity of coal available in the Permo-Carboniferous Coal Measures of New South Wales. The first of these was made by the late Government Geologist (Mr. C. S. Wilkinson), who, assuming 4,000 feet as the limit of depth at which economical mining could be carried out, and allowing one-fifth for loss in working, estimated an available supply of 78,198,000,000 tons of coal. He excluded seams less than $2\frac{1}{2}$ feet in thickness. In 1890, Professor T. W. E. David, taking the same limit of depth, but excluding seams under 3 feet in thickness, arrived at an estimate of from 130,000,000,000 to 150,000,000,000 tons. Still later in 1901, Mr. E. F. Pittman, Government Geologist, with more accurate data as to the area over which the coal measures occur, viz., an area of 16,550 square miles, and assuming an average thickness over this area of 10 feet of workable coal, reduced the above estimate to 115,346,880,000 tons. The estimate of the thickness of coal used in making this calculation is a very conservative one. The output for the past six years has been as follows:—

1907 ..	8,657,924 tons	1910 ..	8,173,508 tons
1908 ..	9,147,025 ..	1911 ..	8,691,604 ..
1909 ..	7,019,879 ..	1912 ..	9,885,815 ..

At this rate of production the estimated available supply would last for over 12,000 years. The follow-

ing table gives analyses of the coal from various localities, the figures given in most cases being an average of a considerable number of analyses; they are taken, for the most part, from Mr. E. F. Pittman's "Coal Resources of New South Wales":—

	Locality.	Water.	Volatile Hydro Carbon	Fixed Carbon	Ash.	Calorimetric value.
Lower Coal Measures.	Hunter River District	1·89	41·35	50·51	6·25	13·2
	Ashford (nr. Inverell)	0·71	22·90	68·96	7·43	13·83
	Clyde River	0·68	34·96	52·92	11·53	.....
Middle Coal Measures.	East Maitland District	1·88	35·71	52·77	9·64	12·5
Upper Coal Measures.	Newcastle District ...	2·01	36·01	53·27	8·71	12·7
	Singleton	1·72	36·76	52·87	8·25	12·7
	Curlewis	2·40	33·30	56·30	8·00	12·0
	Gunnedah	2·55	35·35	55·35	6·75	12·3
	Lithgow District ...	2·05	32·31	53·08	12·56	11·9
	Illawarra	0·71	23·65	63·98	11·66	12·68
	Sydney... ..	0·66	17·57	71·09	10·68	13·0

It will be seen that the coals are all anhydrous bituminous coals, and show a considerable variation in the relative proportions of fixed carbon and the volatile hydro-carbons. These varieties include excellent steam, gas-making, coking, and household coals; it is apparent, therefore, that New South Wales possesses excellent coal resources, both from the point of view of quantity and quality, and as they are at the same time very favourably situated for commercial purposes, they form a great national asset.

Kerosene Shale.—This substance occurs more extensively in New South Wales than perhaps in any other part of the world. It is found both in the Upper and Lower Coal Measures, but the more ex-

tensive deposits occur in the former formation. In nearly all cases the deposits occur at or near the edges of the coal basin; it would seem, therefore, that the edges of the coal measure swamps provided the necessary conditions for the deposition of this material.

The most extensive deposit at present known is that now being opened up at Wolgan, some miles to the north of Lithgow. The main tunnel here has exposed a seam with an average thickness of over 4 feet for a horizontal distance of over 4,000 feet, two-thirds of this thickness being of first grade quality; ordinary coal also occurs in this seam, both above and below the kerosene shale. Kerosene shale also occurs at many other places in the Western district, including Katoomba, Hartley Vale, and Capertee Valley, at some of which it has been extensively mined. Important deposits have also been worked at Joadja, near Mittagong, in the south-western coal-field, and at Mount Kembla, in the Illawarra district, and an extensive deposit is now being opened up at Murrurundi.

The New South Wales production of kerosene shale to the end of 1912 was 1,651,434 tons, valued at £2,322,830.

Kerosene shale is a close-grained, brownish-black rock, with a peculiar toughness, and a well-marked conchoidal fracture. In composition it differs markedly from coal, in containing a very high percentage of volatile hydrocarbons, and a correspondingly low percentage of fixed carbon, as will be seen

from the following analyses of samples of high-grade material from various localities in New South Wales.

	Water.	Volatile Hydro- Carbons.	Fixed Carbon.	Ash.
Torbane	0.72	69.69	9.04	20.54
Jaodja	0.16	89.59	5.27	4.98
Capertee Valley ...	0.30	64.40	13.85	21.45
Wolgan	0.30	67.92	11.98	19.80
Hartley Vale ... ..	...	82.24	4.97	12.79
Mount Victoria ...	0.47	67.45	14.63	17.45
Katoomba	0.30	74.10	13.08	15.52

The average of the analyses from 61 New South Wales samples from various localities gives 69.85 per cent. of volatile hydrocarbons and 14.10 per cent. of fixed carbon, or a ratio of about 5 to 1. With an increasing proportion of fixed carbon, kerosene shales merge gradually into cannel coals; inferior grades contain increasingly higher percentages of inorganic material (ash).

The mode of occurrence is similar to that of ordinary coal, the two often occurring in one and the same seam, it being not uncommon for the kerosene shale to have a layer of coal both above and below it. The area over which it occurs is seldom extensive, as it sooner or later merges into, and gives place to, ordinary coal. The microscopic structure and composition of kerosene shale indicate that it has resulted from the accumulation of an ulmic precipitate, together with seed-spores, pollen grains, and other vegetable debris. The plant-remains include fronds of

the genus *Glossopteris*, sometimes in considerable abundance.

It seems probable, therefore, that near the borders of the coal-measure swamps expanses of open water occurred, comparatively free from the usual coal-making vegetation. Upon the surface of this water showers of spores and pollen grains fell from the surrounding vegetation, while the water itself was more or less charged with organic material in solution. These materials slowly accumulated at the bottom of the swamp, and as they had a different chemical composition from that of ordinary plant fibre, the resulting rock (kerosene shale) has a correspondingly different composition from that of ordinary coal.

Clays.—The shales of the coal-measures include some beds of shale which are very suitable for making bricks, pottery, &c. These are being utilised to a considerable extent in the Lithgow district.

III.—THE PERMO-CARBONIFEROUS GLACIATION.

Nature and Extent of the Glaciation.—The occurrence of glaciated pebbles and erratics in both the Lower and Upper Marine Series has already been referred to. This glacial horizon is not confined to New South Wales, but occurs also in Victoria, Tasmania, South Australia, and Western Australia, and is one of the most interesting features of the Permo-Carboniferous Period in the Southern Hemisphere.

As already pointed out, the glacial beds of the Hunter River district in New South Wales are not typical boulder clays or till, but are marine sediments

into which glaciated pebbles and large erratics were dropped by floating ice as the sediments accumulated. No actual glaciers are known to have existed in New South Wales, but the nature of some of the transported boulders, Devonian quartzite and Silurian limestone, suggests that they may have been derived from corresponding formations in this State. In Victoria, Tasmania, and South Australia, however, the glacial deposits are true moraine deposits, which rest upon glaciated land surfaces. At Bacchus Marsh, in Victoria, fresh-water sandstones, containing *Gangamopteris* and *Schizoneura*, are interstratified with the glacial deposits. In the Inman Valley in South Australia the removal of the glacial deposits is re-exposing the Permo-Carboniferous valley down which the one-time glacier flowed. In West Australia the glacial beds are analogous to those of New South Wales. There can be no question, therefore, that glaciers existed on the Australian Continent during at least part of the Permo-Carboniferous Period; that these glaciers extended at times down to sea-level is shown by the fact that glaciated pebbles and erratics were transported by floating ice and distributed over the bottom of the shallow Permo-Carboniferous sea.

This Permo-Carboniferous glaciation was not limited, however, to Australia; in Peninsular India (Gondwana Series), in South Africa (Dwyka Series), and in Brazil, glacial deposits analogous to those of Australia are found, in each case associated with strata containing the characteristic *Glossopteris* flora. The boulder beds of all these regions, and the

glaciated land surfaces upon which they rest, are just such evidences as those upon which the existence of the Pleistocene Ice Age of the Northern Hemisphere depends, the reality of which is universally accepted. The conclusion has been generally arrived at, therefore, that a glacial period existed in the Southern Hemisphere during the Permo-Carboniferous Period.

The complete change in the flora which ushers in the Permo-Carboniferous Period in Australia is quite in harmony with this view. The marine fauna, however, does not lend the same support. The absence of reef-building corals is, of course, significant; but there is not that marked difference between the marine faunas of the Carboniferous and Permo-Carboniferous Periods which might have been expected had there been a refrigeration of the climate, such, for example, as that which produced the Great Ice Age of the Pleistocene Period. On the contrary, the glacial boulder beds of the Irwin and Gascoyne River Districts of West Australia occur in a marine series of strata which contains a remarkable commingling of the Carboniferous and Permo-Carboniferous marine faunas of New South Wales; a similar commingling of these two faunas appears to exist to some extent in Queensland also. This shows that the change from one fauna to the other was a gradual one, and not a sudden one as might be expected if it were due to a sudden change to a colder climate. In the northern hemisphere, on the other hand, the palæontological evidence of the Pleistocene Period strongly supports

the theory of an Ice Age. While it must be admitted that extensive glaciers existed in Australia during the Permo-Carboniferous Period, and that many of these glaciers extended down to sea-level, it is improbable that Australia, during any part of this period, was buried under an ice-sheet or succession of ice-sheets analogous to those which submerged such a large portion of the Northern Hemisphere during the Pleistocene Ice-Age.

The transportation of glacial material by floating ice extended as far north as the Bowen River in Queensland, and the Gascoyne River in West Australia, but the existence of land ice is not known for certain from further north than Derrinal in Victoria and the Inman Valley in South Australia. The direction of the striae on the glaciated land surfaces indicates a general northerly direction of movement for these glaciers.

Cause of the Glaciation.—The cause of this glacial period, and particularly its peculiar localisation, is one of the outstanding problems of geology. The conditions which produced the Pleistocene glaciation were world-wide in their effect, and the areas most strongly affected were more or less circumpolar. In the Permo-Carboniferous Period, on the other hand, the regions affected were for the most part in the Southern Hemisphere, and in India glaciers, extending nearly to sea-level, existed within a few degrees of the equator. The distribution of land and sea at this time was possibly an important factor. The remarkable similarity of the floras of Australia, India, and South

Africa at this time leads to the inference that these regions, now so widely separated, were joined by direct land connections, and formed parts of a continent, covering part of what is now the Indian Ocean; this supposed continent has been named Gondwana Land. There are also reasons for thinking that Australia at this time had direct land connection with Antarctica and thence to South America. With this distribution of land and sea there must have been a very different oceanic circulation to that which exists at the present day, a condition of things which must have had some corresponding influence on the climate. This factor, in itself, was probably not the main one in producing the glacial conditions, but was most likely a strong contributing cause working in conjunction with other factors which are still unknown.

SUMMARY OF THE PERMO-CARBONIFEROUS PERIOD:

No very definite information is yet available as to the earth movements which took place at the close of the Carboniferous Period in New South Wales. An unconformity exists between the strata of this and the next period, but is not very pronounced in some of the places where junctions between these two formations are definitely known to occur. The uplift which did take place at the close of the Carboniferous was later followed by a subsidence which allowed an extensive transgression of the sea to take place. The limits of this sea are not definitely known, but it certainly covered a considerable portion of what is now the Hunter River district, as well as large areas between

there and the Queensland border. One of these areas extended from the coast at the mouth of the Macleay River westwards to the main tableland; a second area occurred in the Drake district near the Queensland border, and extended westwards at least as far as Emmaville. What the limits of these transgressions of the sea were, and whether they were separate inlets or portions of one continuous sea, is not yet known, but the areas covered are shown approximately in Fig. 37. These marine conditions at the beginning of the Permo-Carboniferous Period were preceded in some localities for a limited time by fresh-water conditions, during which some fresh-water beds (including a coal seam in one case) were deposited; the places where this occurred seem to have been limited in area.

In this epicontinental sea was deposited that thick series of marine sediments known as the Lower Marine Series, all of which must have been laid down in comparatively shallow water. Floating ice, derived perhaps from glaciers in Victoria and Tasmania, drifted northwards on the surface of this sea, dropping, as it melted, its load of morainic material into the marine sediments as they were being deposited. The water of this sea was inhabited by an exceedingly numerous and varied marine invertebrate fauna whose hard parts have been beautifully preserved in many of the strata. At certain localities the remains collected in such abundance as to form beds of limestone. From time to time this tranquil deposition of sediments was interrupted by volcanic

eruptions on a considerable scale, as a result of which extensive lava flows were poured on to the surrounding sea bottom, while immense quantities of volcanic ash were distributed far and wide. The volcanic cones from which these eruptions took place probably stood as islands in this shallow sea. To allow of the deposition of such a great thickness of shallow-water marine sediments (4,600 feet) as was deposited during the Lower Marine Epoch, a more or less continuous subsidence must have been slowly taking place.

An upward movement of the earth's crust now followed, which brought about the entire withdrawal of the sea, converting some of the areas previously covered by it into dry land, but converting the southern area (Hunter River District) into a large fresh-water lake. This extended in a north-westerly direction at least as far as Muswellbrook, but how far south and south-west is not at present known. A smaller lake extended from Inverell to the Queensland border (see Fig. 42). In these lakes the shales, conglomerates, and coal-seams which constitute the Lower Coal Measures were deposited. Twice during this epoch the water shallowed sufficiently to allow of the whole area becoming covered by dense vegetation whose accumulated remains formed two seams of coal with an aggregate thickness of about 40 feet. This thickness of coal would have required a thickness of at least 280 feet of vegetable material for its formation, the growth and accumulation of which must have required a very long period of time.

Renewed subsidence now again allowed the sea to invade the land. This second transgression did not reach its maximum extent until fairly late in the Upper Marine Epoch, when the sea extended over the area approximately shown on the map. (Fig. 51.) The area then covered did not coincide with that covered by the Lower Marine transgression, as will be seen by comparing Figs. 37 and 51. The Devonian and Silurian strata covered by the Upper Marine deposits in the southern and western parts of the area affected had been undergoing denudation during the Carboniferous Period and the earlier part of the Permo-Carboniferous Period; this resulted in the development of an extensive peneplain in these rocks, and exposed the granite bosses by which they had been intruded at the close of the Devonian Period. (See Fig. 63.) As the sea now slowly advanced on the land, the waves worked over the regolith on this old land surface and produced the thick basal conglomerates which mark the base of the Upper Marine Series in these regions.

This re-advance of the sea was accompanied by a marine fauna similar to that which had inhabited it during the Lower Marine Epoch; very few of the species of the older fauna failed to re-appear, and but few new species had developed in the meantime. That glaciers still existed (or had re-appeared) is evidenced by the erratics which occur in the Upper Marine sediments. Vulcanism still continued, but the centre of activity had shifted to what is now the Illawarra district. From one point of eruption near Kiama a

great series of basic lavas and tuffs was poured out; at first great showers of volcanic ash, large blocks and bombs rained down into the sea, causing a wholesale destruction of the animals by which it was inhabited, then followed great floods of molten lava which spread far and wide over the sea bottom. After these eruptions had been in progress for some time, a second centre of activity developed some few miles to the south at Cambewarra, from which trachytic lavas and tuffs were ejected. The volcanic activity in these regions continued until the close of the epoch.

The development of a land barrier to the east now cut off the Upper Marine Sea from the ocean and converted it into a fresh-water lake in which the Upper Coal Measures were deposited. The great thickness of these beds, and the fact that throughout they evidence shallow-water conditions of deposition, show that a slow subsidence was in progress. Each coal-seam indicates a period of comparative rest from the downward movement, during which the waters silted up and became sufficiently shallow to allow of a dense growth of swamp vegetation extending far and wide over its surface. Sooner or later renewed subsidence carried the accumulation of vegetable material beneath the water, and brought about the deposition on top of it of beds of shale, sandstone, and conglomerate. Volcanic eruptions still continued; in the Newcastle district, showers of the finest volcanic dust from time to time rained down into the coal-swamps, while in the Murrurundi and Illawarra districts basic lava-flows were poured out at intervals over the lake-bottom.

It will be seen from what has already been stated that a subsidence area developed in the eastern part of New South Wales at the beginning of, and continued more or less throughout, the Permo-Carboniferous Period. That the area affected and the extent of subsidence varied in different parts of the regions named is shown by the following table giving the formations deposited in the respective areas, together with their thicknesses:—

	Hunter River District.	Illawarra District.	Lithgow District.	Drake District Macleay River area.
Upper Coal Measure	ft. 1,500	ft. 850	ft. 480	Absent
Dempsey Series ...	2,000-3,000	Absent.	Absent	do
Middle Coal Measure	800-1,700	do	do	do
Upper Marine Series	6,400	3,200	400	do
Lower Coal Measure	300	150	Absent.	do
Lower Marine Series	4,800	Absent.	do	Present (thickness unknown).
Total Thickness ...	17,700	4,200	880	Unknown.

The apparently permanent retreat of the sea at the close of the Lower Marine Epoch from the areas covered by it in the Emmaville, Drake, and Macleay River districts suggests that some important earth movements may have affected these regions at that time. This is supported by the fact that the Lower Marine strata here are much more highly folded than those of the Hunter River district, and that they have been extensively intruded by plutonic igneous rocks. The overlap of the Upper Marine strata on the Lower Coal Measures and Lower Marine Series at several

places in the northern edge of the Maitland coal-field lends further support to this view. It would appear probable, therefore, that at the close of the Lower Marine Epoch (or perhaps Lower Coal Measure Epoch) the north-eastern part of the State was subjected to orogenic earth-movements which folded the Lower Marine strata and lifted them above sea-level. The folding was accompanied by the intrusion of plutonic igneous rocks. The strength of this movement decreased southwards, and died out as the present Maitland district was approached, the only effect here being to cause a slight overlap of the Upper Marine Series on the earlier Permo-Carboniferous strata. Renewed orogenic earth-movements took place in the same region at the close of the Permo-Carboniferous Period, and this time extended sufficiently far southward to develop a series of broad anticlinal and synclinal folds in the Permo-Carboniferous strata along the northern edge of the Maitland coal-field. Only one of these folds (the Lochinvar Anticline) extends much to the south of the present course of the Hunter River, and even this soon flattens out and disappears. This was the last occasion upon which orogenic earth-movements are known to have affected any part of New South Wales. The Permo-Carboniferous strata of the southern and western coal-fields were not affected by these orogenic movements.

CHAPTER XI.

TRIASSIC AND JURASSIC PERIODS.

ABOVE the Permo-Carboniferous formation described in the last chapter, there is found in New South Wales an extensive series of fresh-water beds, which rest conformably, for the most part, upon them, but which contain a distinctly different fossil flora; this flora is of undoubted Mesozoic age. These fresh-water beds are overlain in turn, in the north-western part of the State, by marine strata of Cretaceous age. As they represent the total sedimentation which took place from the close of the Palæozoic Era until the beginning of the Cretaceous Period, they are generally, in Eastern Australia, referred to as the Trias-Jura formation. It is considered by some authorities that part of these fresh-water beds in New South Wales (the Hawkesbury Series) are of Triassic age, while the remainder (Clarence Series and Artesian Series) are considered to have been deposited later; these they consider to be of the same age as the so-called Trias-Jura beds of the neighbouring States of Queensland and Victoria. The reasons for this will be discussed later.

The Triassic and Trias-Jura formations in New

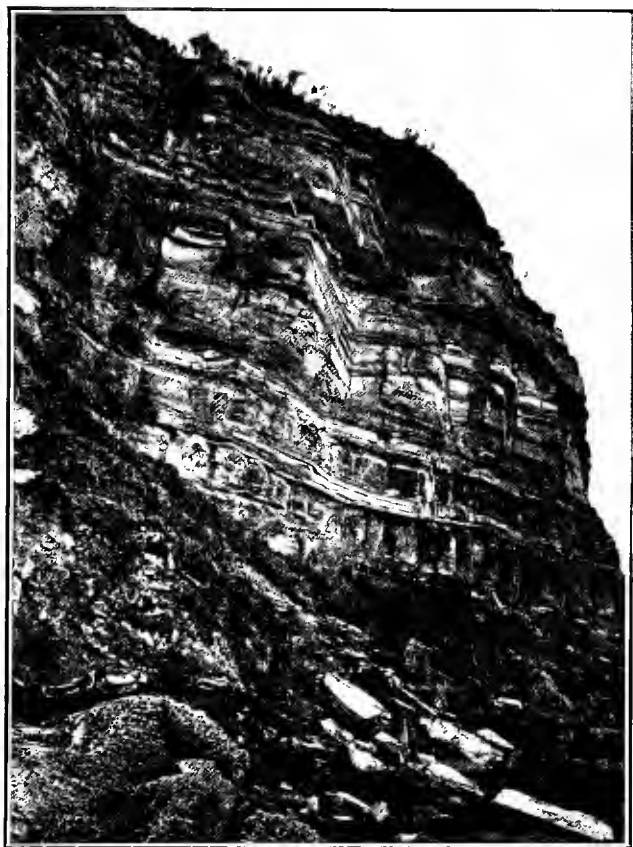


Fig. 61.

Narrabeen Beds (Shales, Sandstones, and Conglomerates), as seen in the Cliff Sections on the coast near Newport.

South Wales occur in several distinct areas, and have been named as follows:—

1. The Hawkesbury Series.
2. The Clarence Series.
3. The Artesian Series.
4. The Talbragar Series.

It will be convenient to describe each series separately, and discuss their relative ages subsequently.

1.—THE HAWKESBURY SERIES.

These overlie, to a considerable extent, the strata of the main Permo-Carboniferous coal-basin of New South Wales. They outcrop along the coast from the Shoalhaven River nearly to Newcastle, and extend westwards to Lithgow. What are said to be outliers of this series occur as far north as Camden Haven and Broken Bargo. Adjacent to Sydney, the base of the series is nearly 3,000 feet below sea-level; southwards, westwards and northwards the strata rise gradually until in the Illawarra Range they reach an altitude of nearly 1,000 feet and at Lithgow over 3,000 feet above sea-level. They cap the greater part of the Blue Mountains tableland.

This series has been sub-divided as follows:—

1. The Wianamatta Stage.
2. The Hawkesbury Stage.
3. The Narrabeen Stage.

The Narrabeen Stage.—The beds belonging to this stage consist of sandstones and shales, with occasional thin beds of conglomerate. They attain their maxi-

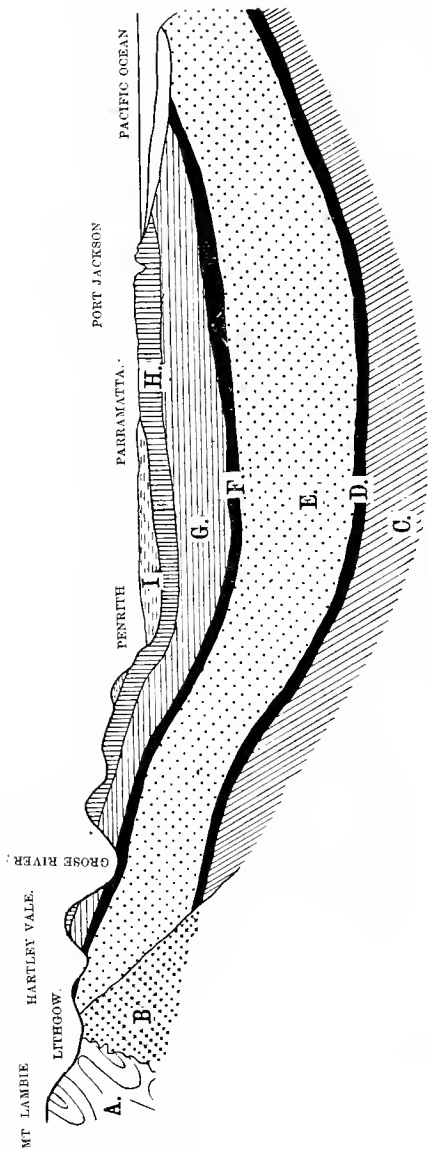


Fig. 62.

Ideal Section from Mount Lambie to the Coast, showing the Permo-Carboniferous and Triassic Basins (Pittman).
 A = Devonian Strata. B = Granite. C = Lower Coal Series. D = Lower Coal Measures. E = Upper Marine Series.
 F = Upper Coal Measures. G = Narrabeen Beds. H = Hawkesbury sandstones.
 I = Wianamatta shales.

imum thickness near Sydney, where, in the Cremorne bore, the following section was proved:—

<i>Hawkesbury Sandstones</i>	1,020 feet
<i>Narrabeen Beds</i> —	
Chocolate shales	170 „
Sandstones, shales and conglomerates	1,082 „
Cupriferous shales	38 „
Estheria shales	561 „
<i>Upper Coal Measures</i> ..	(thickness unknown)

The Estheria shales are so called because some of the beds contain immense numbers of a small phyllopod of that name; beds of sandstone and conglomerate are interstratified with these shales. The cupriferous shales which follow are probably redistributed tuffs, and contain a small percentage of copper, too small, however, to give the beds any commercial value. Following these there is a thick series of conglomerates, sandstones and shales, the latter containing abundant fossil plants. The chocolate shales, which occur at the top of this stage, are also redistributed tuffs, and have a characteristic chocolate-red colour which, together with their peculiar lithological characters, enables them to be readily identified. As this bed maintains these characters over the whole of the area in which the Hawkesbury Series occur, it is a useful “persistent horizon” in mapping these beds. These chocolate shales outcrop strongly on the coast at Narrabeen, a few miles north of Sydney, from whence the formation gets its name.

When followed westwards, the Narrabeen beds are

found to thin considerably, as will be seen from the following sections taken from various localities at increasing distances westwards from Sydney:—

	Cherome Bore, Sydney.	Morebank Bore.	Euroka Bore.	Woodford Bore.	Clarence Bore.	Lithgow.
	ft.	ft.	ft.	ft.	ft.	ft.
Hawkesbury Sandstone Stage	1,100	1,000	272	284	191	135
Narrabeen Stage—						
Chocolate shales... ..	170	} 744	} 1,165	} 921	} 355	} 241
Shales and sandstones ..	1,082					
Copper shales	38	} 749				
Estheria beds	561					
Totals (Narrabeen Stage) ...	1,851	1,493	1,165	921	355	241

In the western part of the Blue Mountains the Narrabeen beds consist mainly of massive sandstones, and the chocolate shale bed (170 feet thick at Sydney) has split into three well-defined bands separated by sandstone, the upper and lower bands being 130 feet apart. These are well shown in the road-cuttings on the Mount Victoria Pass. On the north-western edge of the basin, at Gunnedah and Murrurundi, beds of conglomerate about 200 feet in thickness occur at the base of the Narrabeen beds. In the south-western part of the basin the Narrabeen beds are missing, having been overlapped by the Hawkesbury sandstones.

Fossil plants are abundant in some of the shales, particularly those near the top of the series, as, for example, in the cliff sections along the coast between Narrabeen and Barranjoey. Ripple-marks, annelid

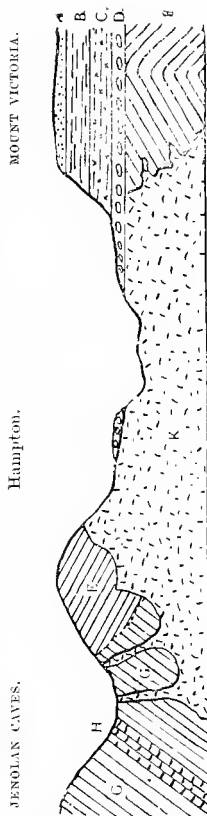


Fig. 63.

Sketch-section (not to scale) from Jenolan to Mount Victoria.

A = Hawkesbury sandstone, B = Narrabeen Beds, C = Upper Coal Measures, D = Upper Marine Series, E = Devonian strata, F = Silurian claystones, G = Silurian claystones, H = Silurian Limestone, I = Silurian claystones, J = Silurian claystones, K = granite.

tracks and burrows, and sun-cracks are common in many of the shale beds, while current-bedding is frequently seen in the sandstones. All these features, together with the occasional occurrence of bands of conglomerate, furnish conclusive evidence of the shallowness of the water in which these beds were deposited.

The Hawkesbury Sandstone Stage.—These beds outcrop strongly along the coast in the neighbourhood of Sydney, and form the surface rock of the greater part of the Blue Mountain tableland. The precipitous wall-like escarpments which this formation presents around the sides of the Blue Mountain valleys is due to the

undermining of the hard Triassic sandstones by the more rapid weathering of the underlying soft shales of the coal measures.

The Hawkesbury sandstone formation consists mainly of massive sandstones and grits, which attain

a maximum thickness of 1,100 feet at Sydney. Occasional thin lenticular beds of carbonaceous shale occur, but are always limited in extent. Current-bedding is a frequent and conspicuous feature in the sandstones, the prevailing direction of dip of the laminae being north-north-east, and the average angle of dip about 20 degrees. It seems obvious from this that the sandstones were deposited in shallow water in which rapidly-moving currents, coming mainly from the south-south-west, were transporting large quantities of sand. Examples of contemporaneous erosion are also not uncommon. Some of the lenticular beds of shale above referred to contain fossil plants, fish, and fresh-water shells (*Unio*), and must have been deposited in small lakes or lagoons temporarily cut off from the main body of water in which the coarser sediments were being deposited. The sandstones vary somewhat in composition—some are very argillaceous, others are the reverse; others again contain much mica; still other beds are very ferruginous; while small flakes of graphite are not infrequently found in many of the strata. Where the Hawkesbury sandstones have been intruded by basalt-dykes, prismatic structure has been developed in many cases, the most notable being that at Bondi.

This has been produced in what were porous sandstone beds, saturated with water at the time the intrusions took place; unequal heating started convection currents which heated the particular sandstone bed for some distance away from the contact, and caused the rock to expand. Subsequent contraction



Fig. 64.

Triassic Sandstones, Valley of the Waters, Blue Mountains.



Fig. 65.
Current Bedding in Hawkesbury Sandstones, Bondi, Sydney.

on cooling developed the joints whose intersection resulted in the prismatic structure. This prismatic structure is always accompanied by a variable amount of secondary silification, which has converted the sandstone into an imperfect quartzite. The altered rock has been much in demand for road-making purposes, and is known to the road-maker as "white metal"; consequently, these interesting occurrences have been in nearly every case quarried out and removed.

Another interesting feature of the Hawkesbury sandstones is the contortion of the laminae in certain of the strata showing current bedding. No really satisfactory explanation of this feature has yet been suggested.

Many excellent beds of "free-stone," ranging up to 60 feet in thickness, are found, and have been extensively quarried for the building of the metropolis. Gold occurs more or less throughout the Hawkesbury sandstones, but the quantity (2 or 3 grains to the ton) is, of course, too small to be of any value; as much as 2 or 3 dwt. per ton has been found in some places, and has given rise to much profitless expenditure of money in prospecting the rocks in such localities.

The Wianamatta Stage.—The strata of this stage consist of a thick series of shales, with occasional bands of sandstone, carbonate of iron, and thin bands of impure coal. The beds attain their maximum thickness in the Pieton and Campbelltown districts where, according to the late Rev. W. B. Clarke, the thickness approaches 700 feet, and the formation includes grits and sandstones. The name Wianamatta,

which was given to them by this geologist, is the native name for South Creek; he recorded from this locality a seam of impure coal, 4 feet in thickness. The Wianamatta shales overlie the Hawkesbury sandstones over large areas, but do not extend so far to the west and north as the latter formation. In the Blue Mountains they have been removed from considerable areas by denudation; the small outliers occurring under the basalt caps at Mounts Tomah and King George, and the larger outlier at Springwood, testifying to the greater area once occupied by these shales in this region.

Small lenticular beds of impure fresh-water limestone occur at Kurrajong, which contain fossil Ostracods and Foraminifera. The fossil fauna found in the Wianamatta shales includes fresh-water fish, pelecypods, and large amphibia (Labyrinthodonts); fossil plants also occur in considerable abundance. The shales provide excellent brick-making material, and are extensively quarried for that purpose in the environs of Sydney: it is from such quarries at St. Peters that specimens of the fossil fish and amphibia have been obtained.

Relation of the Hawkesbury Series to the Upper Coal Measures.

Throughout the greater part of the area over which the Hawkesbury Series occur, they rest conformably upon the Upper Coal Measures, so that the Triassic sedimentation seems to have followed that of the Permo-Carboniferous without any interruption; it is

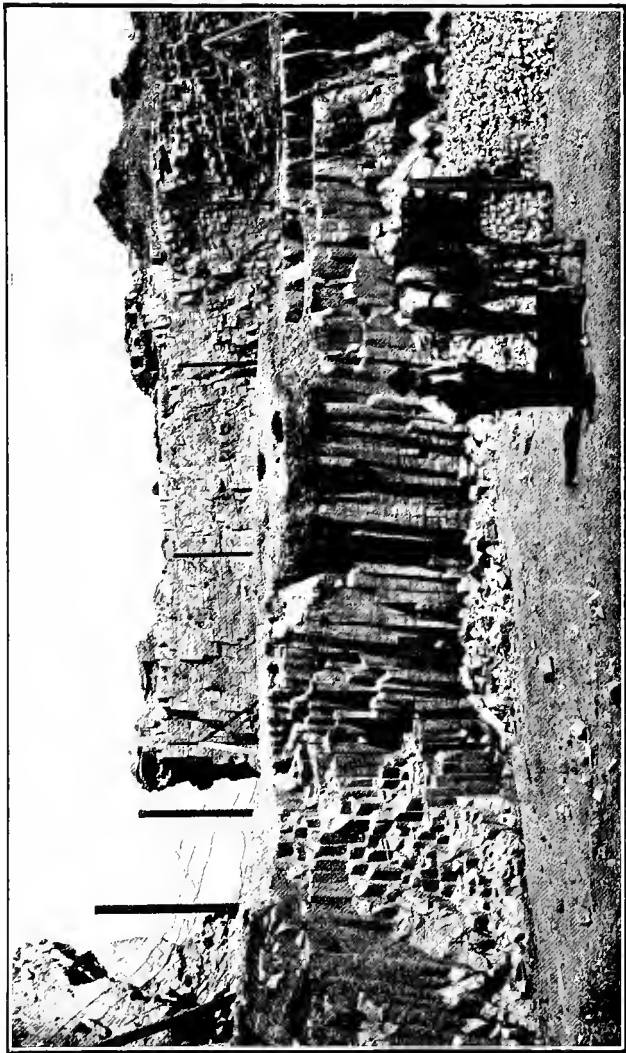


Fig 66.
Prismatic Sandstone, Bondi, Sydney.

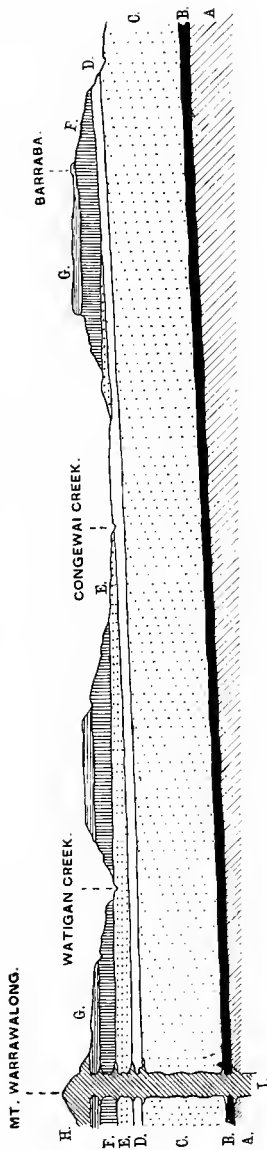


Fig. 67.

Section showing an unconformity between the Triassic and Perno-Carboniferous Strata near Ellalong. (After David).

A = Lower Marine Series, B = Lower Coal Measures, C = Upper Marine Series—Branxton Beds, D and E = Upper Marine Series—Muree Beds, F = Triassic—Narabeen Beds, G = Triassic—Hawkesbury sandstones, H = Basalt, I = Probable volcanic neck.

a matter of difficulty to fix the dividing line between the two formations. At Ællalong, however, on the northern edge of the basin, a well-marked unconformity occurs, as may be seen from the section. (Fig. 67.).

A comparison of the floras of the two periods has already been made on page 137 wherein it was shown that, although a marked difference exists, a slight commingling of them occurs at the junction of the two formations.

Life of the Triassic Period (Hawkesbury Series).

(A.) Fossil Plants.

Equisetales.—*Schizoneura australe*, *Phyllothea Hookeri* (*P. concinna*), *Equisetum*.

Filicales—*Thinnfeldia odontopteroides*, *Thinnfeldia narrabeenensis*, *Sphenopteris*, *Alchopteris* (*Cladoplebis*) *australis*, *Macrotæniopteris Wianamattæ*, *Olcandridium lenticuliforme*, *Stenopteris rigida*, *Cycadopteris scolopendrina*, *Tæniopteris*.

Cycadales—*Podozamites lanceolatus*.

Ginkgoales—*Ginkgo dilatata*, *Baiera multifida*.

Coniferæ—*Araucarites*.

(B.) Fossil Fauna.

Foraminifera — *Nubecularia*, *Haplophragmium*, *Endothyra*, *Discorbina*, &c.

Pelecypoda—*Unio*, *Unionella*.

Crustacea (Ostracoda) — *Beyrichia*, *Darwinula*, *Cytheridæ*.

Crustacea (Phyllopoda)—*Estheria*.



Fig. 68.

Triassic Plant. *Thinnfeldia odontopteroides*.

Pisces (fish)—*Palaeoniscus*, *Myriolepsis*, *Cleithrolepis*, *Pleuracanthus*, *Elonichthys*, *Gosfordia*, *Apateolepis*, *Dietyopyga*, *Sagenodus*, *Accentrophorus*, *Belonorkyneus*, *Semionotus*, *Pristisomus*, *Elpisopholis*, *Pholidophorus*.

Amphibia (Labyrinthodonta) — *Mastodonsaurus*, *Platyceps*.

THE EQUISETALES.—*Schizoneura* had already appeared before the close of the Permo-Carboniferous; it continued on into the Triassic, but soon became extinct. *Phyllotheca*, on the other hand, continued to flourish luxuriantly throughout the Triassic. *Equisetum* makes its first appearance here.

THE FILICALES.—*Thinnfeldia* is the largest and most abundant of these; the size of the frond and the shape of the pinnules varied considerably, but the frond itself was always dichotomous. Among the many thousands of these which have been collected, not one fertile frond has yet been observed, and it is more than probable that this so-called fern is the vegetation of some more highly organised plant. Specimens of an inflorescence have been found associated with *Thinnfeldia* both at Mount Piddington and at Narrabeen, which possibly may have been derived from the same plant. *Macrotæniopteris* and *Oleandridium* are more characteristic of, and are fairly abundant in, the Hawkesbury Series.

THE FISH.—These occur on three distinct horizons—1st, the Hawkesbury Sandstone Stage, at Gosford; 2nd, the Wianamatta Stage, at St. Peters (near Syd-

ney), and at Mittagong; 3rd, the Talbragar beds on the Talbragar River, near Gulgong; the latter beds have been referred to the Jurassic period by some writers. There is some doubt as to whether the Gosford fish-beds are near the base of the Hawkesbury sandstones, or near the top of the Narrabeen beds. The fossil fish genera described from the localities are as follows:—

	Hawkesbury Stage (Gosford).	Wianamatta Stage (St. Peters).	Talbragar Beds (Jurassic).
Elasmobranchii	(An imperfect specimen).	<i>Pleuracanthus</i>	
Dipnoi	<i>Gosfordia</i>	<i>Sagenodus</i>	
Teleostomi (Actinopterygii)	<i>Myriolepis</i> <i>Semionotus</i> <i>Cleithrolepis</i> <i>Pholidophorus</i> <i>Apateolepis</i> <i>Dictyopyge</i> <i>Belenorhynchus</i> <i>Pristisomus</i> <i>Peltopleurus</i>	<i>Myriolepis</i> <i>Semionotus</i> <i>Cleithrolepis</i> <i>Pholidophorus</i> <i>Acetrophorus</i> <i>Platysomus</i> <i>Elipsopholis</i> <i>Elonichthys</i> <i>Palæoniscus</i>	<i>Coccolepis</i> <i>Aphnelepis</i> <i>Aetheolepis</i> <i>Archæomene</i> <i>Leptolepis</i>

The Gosford fish are all regarded as being homotaxial with the Triassic of Europe; the assemblage of fish from the Wianamatta shales at St. Peters, however, is remarkable, in that it displays an astonishing commingling of European Palæozoic and Mesozoic genera. Such genera as *Pleuracanthus*, *Sagenodus*, *Elonichthys*, *Platysomus*, *Palæoniscus*, *Acetrophorus*, and *Elipsopholis* range in Europe from Lower Carboniferous to Permian, and do not pass upwards beyond the Palæozoic. On the other hand, *Semionotus*, *Cleithrolepis*, and *Pholidophorus* are typical of the Mesozoic in Europe. This seems all the more strange when one remembers that at Gosford, which



Fig 69.
A Triassic Fish, *Pleuracanthus*, restored. (After Smith-Woodward).

is on a lower horizon, only Mesozoic types occur. The Talbragar fish seem to have their nearest allies in the Jurassic of Europe. *Pleuracanthus* appears to have been the largest of these Triassic fish, and attained a length of nearly 6 feet.

THE AMPHIBIA.—These had already made their appearance before the close of the Permo-Carboniferous, but the Triassic examples are larger; one undescribed *Mastodonsaurus* (a Labyrinthodont), from the St. Peters fish beds, has a length of quite 12 feet.

THE CRUSTACEA.—*Estheria* was the most important genus, and occurred in enormous numbers in the early part of the period.

THE FORAMINIFERA.—The occurrence of Foraminifera in small lenticular beds of limestone near the top of the Wianamatta shales, near Kurrajong, is a remarkable anomaly. It has always been taken for granted that Foraminifera are limited in habitat to the sea:

yet here we have them occurring in a formation whose every other character supports the belief that these beds were formed in a fresh-water lake. Did these organisms actually live in fresh water during this epoch, or was there a temporary inroad of the sea? Had the latter been the case one would have expected more evidence than the presence of a few fossil foraminifera gives.

2.—THE CLARENCE SERIES.

These also are fresh-water beds occurring in the form of a basin in the north-east corner of New South Wales. They outcrop strongly over the eastern part of the watershed of the Clarence River and along the coast from Woolgoolga to the mouth of the Richmond River; northwards they cross into Queensland, and are continuous with the Ipswich beds of that State. At Grafton, which is at about the centre of the basin, a borehole put down in search of artesian water passed through a thickness of 3,700 feet of these beds, and was still in them when boring ceased. The Clarence Series have been subdivided as follows:—

Upper Clarence Beds	..	Shales, &c.
Middle	..	Massive sandstones
Lower	..	Shales and sandstones with coal seams, conglomerate.

The conglomerates at the base of the series are very thick, and outcrop strongly around the western edge of the basin; they are auriferous at Pretty Gully.

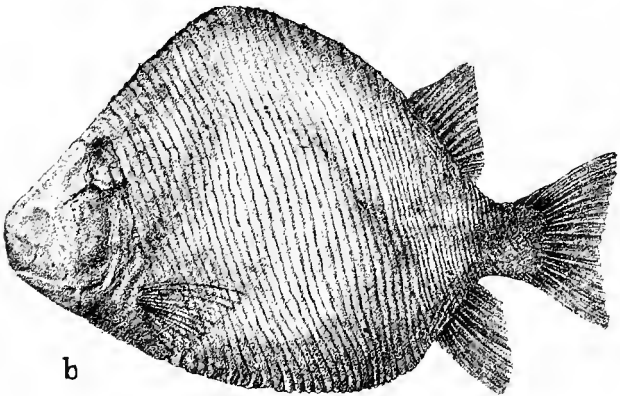
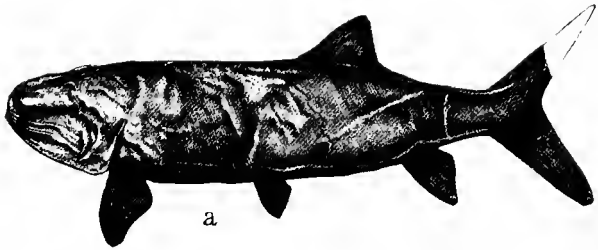


Fig 70.

New South Wales Triassic Fish.

a. *Myriolepis Clarki*. b. *Cleithrolepis granulatus*.

about 15 miles from Drake, but not payably so. Five seams of coal occur in the Lower Clarence Series above the conglomerates, and range from 2 to 37 feet in thickness. So far as these seams have been prospected, they appear to contain too many clay-bands for the coal to have much economic value, except, perhaps, for local purposes. The sandstones of the Middle Clarence Beds have a strong lithological resemblance to those of the Hawkesbury Series, and on that account it has been suggested that the Lower, Middle, and Upper Clarence beds are the equivalents of the Narrabeen, Hawkesbury Sandstone, and Wianamatta stages of the Hawkesbury Series. The fossil flora of this series possesses some differences from that of the Hawkesbury Series, but is quite similar to that of the Ipswich Beds of Queensland and the Trias-Jura Beds of Victoria; it is characterised by the relatively great abundance of *Tæniopteris Daintrei*, which has not yet been found in the Hawkesbury Series. Several species of *Thinnfeldia* are present, but the genus is more variable and the fronds more delicate than those from the Hawkesbury Series. *Thinnfeldia* of the true Hawkesbury type, as well as *Macrotæniopteris*, have, however, been found near the base of the series; coniferous wood occurs in abundance.

3.—THE ARTESIAN SERIES.

Fresh-water beds of Trias-Jura age outcrop along the western edge of the New England Table-

land, from Dubbo northwards past Narrabri and Warialda to the Queensland border. Here they join on to the Ipswich beds, and are thus linked up by way of Queensland with the Clarence Series. The width of outcrop of the artesian beds (the intake beds) in an east and west direction is, on the average, about 60 miles, beyond which they dip westwards beneath Cretaceous marine strata. Further to the west they have been met with at considerable depths in the bore-holes put down to tap the artesian water which they contain. As they have been intersected at localities as far apart as Moree, Coonamble and Nyngan, these Trias-Jura strata must underlie the Cretaceous system over a very large area in north-west New South Wales, an area estimated by Mr. E. F. Pittman as being about 83,000 square miles. The correlation of these beds with the Clarence Series is based, firstly, on the occurrence in both of them of *Terniopteris Daintrei*; and secondly, on the fact that, as already stated, they are actually linked up with them by way of the Ipswich beds, in Queensland. The occurrence of artesian water in these strata is of the very highest importance to this part of New South Wales, which has a low average rainfall, and is subject to long periods of drought. Many artesian wells have been sunk throughout this region, ranging up to nearly 4,000 feet in depth, from which flows of water have been obtained in the case of individual bore-holes up to 3,000,000 gallons per day. The water from some of the deeper bores has a fairly high temperature, 115° F. in the case of the Moree bore,

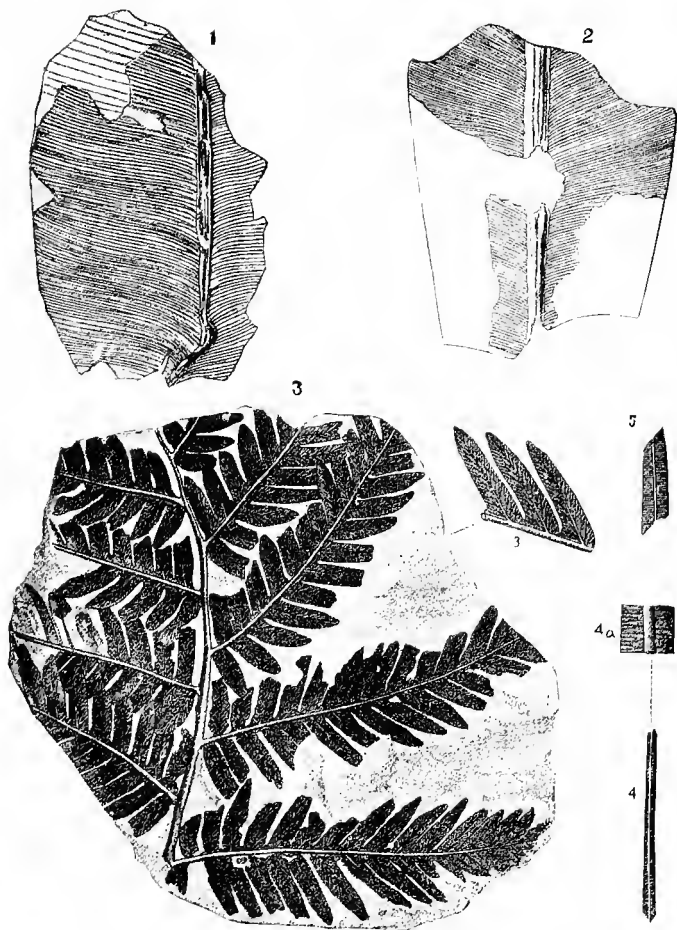


Fig. 71.

Triassic and Trias-Jura Plants.

1-2. *Macrotentopteris Wianamutae*. 3. *Alethopteris australis*. 4-5. *Tacniopteris Daintrei*.

and although the bore water generally contains a fair percentage of mineral matter, it has proved to be excellent for stock. Its use for agricultural purposes is not altogether so satisfactory, as, after it has been used for a few years, the soil becomes too highly charged with the mineral substances brought on to the land by the bore water. Upwards of 160 wells have been put down to date; but some of them are at present providing a considerably diminished supply as compared with that given at first; whether this is due to exhaustion in the artesian beds, or to the partial caving in of the bore-holes, has not yet been determined.

Until a few years back it had always been assumed that the water obtained from this artesian basin was of meteoric origin, *i.e.*, had fallen as rain upon the outcropping edges of the Triassic strata (intake beds), had percolated downward through the more porous beds and had collected in the deeper part of the basin. Under these conditions the supply of water would be undergoing a constant replenishment from rainfall and might be looked upon as being permanent. It has been suggested by Prof. J. W. Gregory, however, that the water is, for the most part, not of meteoric origin, but of magmatic origin, *i.e.*, has been given off during the cooling of a deep-seated mass of igneous rock (magma) and, as it travelled upwards, collected in the porous strata of the Trias-Jura fresh-water beds. The importance of this theory, if correct, is that it puts some limit to the amount of water available, as, under the conditions supposed.

the supply will not be indefinitely renewed, and is therefore being constantly reduced in amount in an increasing ratio as more and more bore-holes are put down. Professor Gregory's theory has not yet been generally accepted by Australian geologists, but he has certainly made out a very strong case. The question is of too technical a character to be discussed here, and the author prefers at present to suspend judgment.

4.—THE TALBRAGAR SERIES.

These occur on the Talbragar River, about 20 miles from Gulgong; they are fresh-water beds about 40 feet in thickness, and the area over which they extend is only a few acres in extent. The lowest beds consist of ferruginous cherty shales, about 10 feet in thickness, literally crowded with fish and plant remains. The plants are preserved in the form of siliceous impressions, their pure white colour being in marked contrast to the yellow colour of the rock on which they occur; the fish also occur as impressions on the shale, in most cases with the bones replaced by ochreous material, and are beautifully preserved. These fish are crowded together as if suddenly destroyed, a feature characteristic of the Gosford fish beds also; this sudden destruction was probably due to a rapid influx of sediment into the lake in which the fish were living. The fish beds are succeeded by white siliceous shales and siliceous ironstone, both of which are unfossiliferous. The Tal-

bragar deposit, as a whole, appears to lie in an erosion hollow in the Hawkesbury sandstones. The

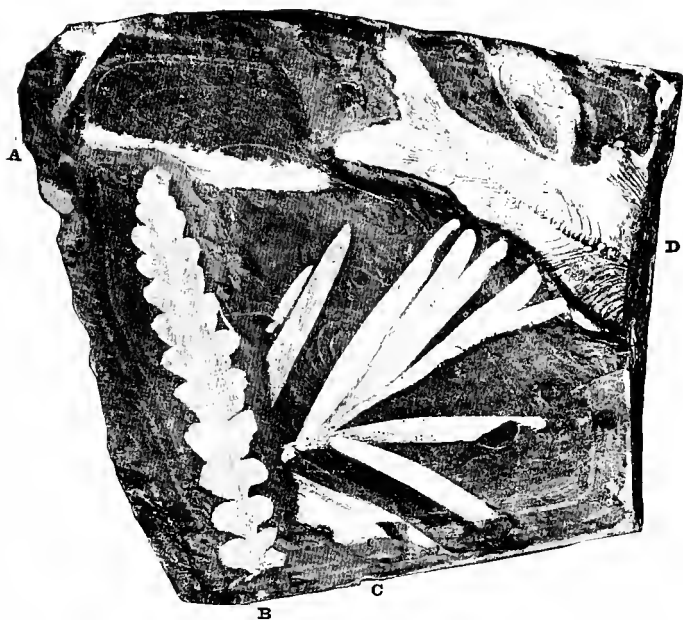


Fig. 72.

Slab of shale from Talbragar with fossil plants and fish.

A.—*Taeniopteris Duietrei*. B.—*Thinnfeldia adiantopteroides*. C.—*Podozamites lanceolatus*. D.—*Coccolepis* (?) a fossil fish.

fossil flora is very similar to that of the Clarence Series; *Podozamites lanceolatus* is particularly abun-

dant, while *Tæniopteris Daintrei* and *Thinnfeldia* are not uncommon. The fish are different from those so far obtained from other Trias-Jura localities in New South Wales, and have their nearest allies in the Lias and Jurassic of Europe; they are listed on page 166.

Correlation of the Hawkesbury, Clarence, Artesian, and Talbragar Fresh-water Beds.—Considerable diversity of opinion exists as to the relative age of the Triassic and Trias-Jura beds from the different localities in New South Wales. The Hawkesbury Series are generally accepted as being of Triassic age; the flora and fauna both support this view, and the absence of any break in the sedimentation in passing from the Permo-Carboniferous strata to the Narrabeen beds (with the exception at Ellalong already mentioned) confirms it. With regard to the Clarence and Artesian Series, however, the view is held by some geologists that these were deposited later than the Hawkesbury Series. It is now the generally accepted view that the Clarence and Artesian Series are of the same geological age as the Ipswich and Burrum formations in Queensland, with which they are, in fact, co-extensive, and of the same age as the Gippsland and Cape Otway beds in Victoria; in both of these States the age of these fresh-water beds is taken as being Trias-Jura. Various arguments have been put forward in support of the view that the Hawkesbury Series are older than the Clarence, Artesian, and Talbragar Trias-Jura beds. Taking the paleontological one first as being the most im-

portant, what differences there are in the fossil floras will be seen from the following lists:—

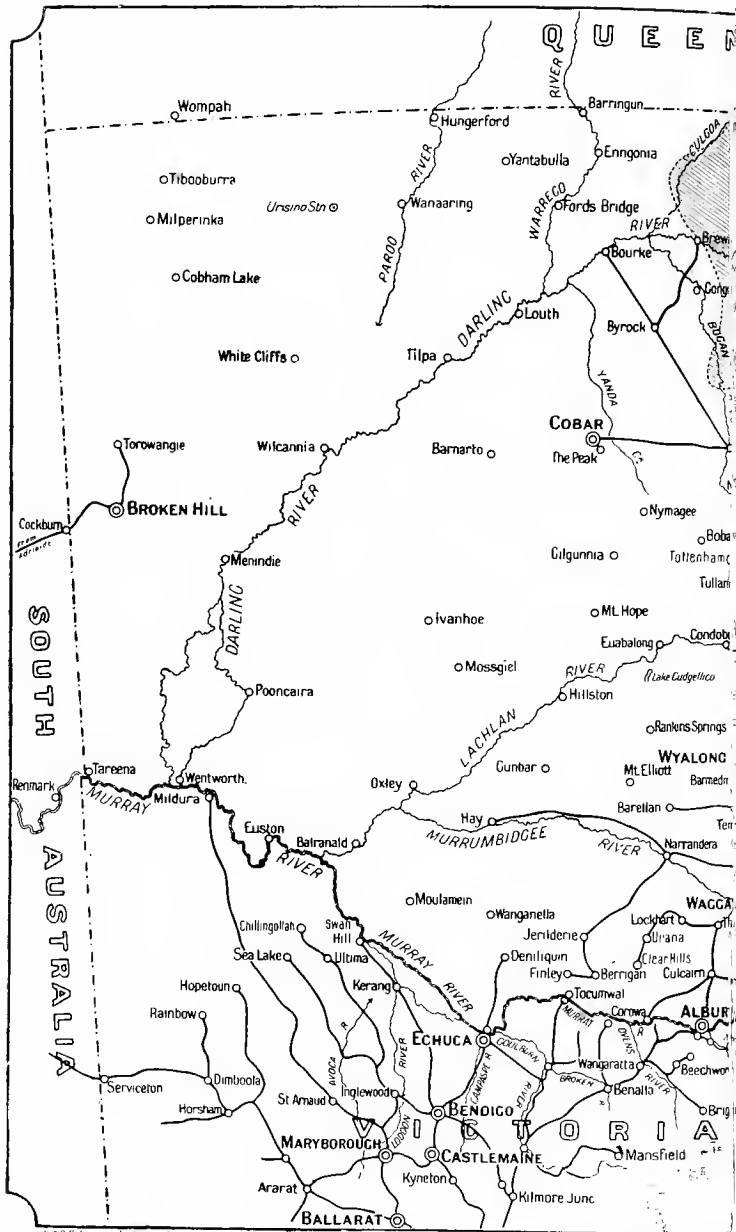
	Hawkes- bury Series.	Clarence and Artesian Series.	Talbragar Beds.	Ipswich Beds.
<i>Schizoneura australe</i>	X	...	...	...
<i>Phyllotheea Hookeri</i>	X	...	...	...
<i>Equisetum</i>	X	...	...	...
<i>Thinnfeldia odontopteroides</i> ...	X	X	X	X
<i>Thinnfeldia Narrabeenensis</i> ...	X	...	...	...
<i>Sphenopteris</i>	X	X	...	X
<i>Alethopteris australis</i>	X	X	X	X
<i>Macrotæniopteris Wianamattæ</i>	X	X	...	...
<i>Oleandridium lenticuliforme</i>	X	...	...	X
<i>Tæniopteris Daintrei</i> ... ..	...	X	X	X
<i>Podozamites lanceolatus</i>	X	...	X	...
<i>Ginkgo dilatata</i>	X	...	...	X
			(or a similar form ¹)	
<i>Baiera multifida</i>	X	X	...	X
<i>Araucarites</i>	X	...	...	...

How far the differences are due to insufficient collecting, or how far they represent real differences in the respective floras, is at present somewhat difficult to decide. The fossil fish of the Talbragar beds belong to genera which have not yet been found in the Hawkesbury Series, and have their nearest allies in the Jurassic of Europe; when one remembers, however, that one particular bed in the Wianamatta shales at St. Peters contains an assemblage of fossil fish quite different from those in another bed in the same quarry, this fact loses some of its weight. The absence of artesian water in the Hawkesbury Series, which occurs in the form of a typical basin, has been urged as a reason why the Hawkesbury Series should

not be of the same age as the Artesian Series. This argument would, however, apply equally well to the Clarence Series, which also occurs in the typical basin form but, as far as is known, contains little or no artesian water. The absence of coal seams in the Hawkesbury Series has been similarly cited as a reason for their greater age; there seems to be no valid reason, however, why sedimentation could not go on in two distinct basins simultaneously with conditions for coal-making favourable in the one locality and unfavourable in the other. At present, therefore, while it may be admitted that there are some differences between the fossils of the Hawkesbury Series and the Trias-Jura beds of New South Wales, it is, perhaps, premature to say definitely that the former were deposited before the latter.

SUMMARY OF THE TRIASSIC AND JURASSIC PERIODS.

The close of the Permo-Carboniferous Period, as already pointed out, was marked in the north-eastern part of New South Wales by mountain-making (orogenic) movements which folded the Permo-Carboniferous sediments as far south, approximately, as the present Hunter River district, where the folding produced an elevation of at least 7,000 to 8,000 feet. These folded strata suffered considerable denudation early in the Triassic Period before the strata of this period were deposited unconformably upon them. To the south and south-west of this region no such earth movements took place, and Triassic sedimentation followed that of the Permo-



H. C. Robinson, 1884, 2, 1253, Geographical Society, Sydney, (Copyright)

Fig. 73.—Map of New South Wales, showing the positions and approximate areas of is shown by the area hatched with oblique lines;

Carboniferous Period without any apparent break. The beginning of the Triassic Period found the whole of New South Wales above the sea, and extending much further eastwards than it does at the present time. Certain large areas remained covered with fresh water, and in these lakes considerable sedimentation took place; it will be convenient to call these three sheets of water the Hawkesbury Lake, the Clarence Lake, and the Artesian Lake respectively. There is no doubt that the first-named existed at the beginning of the period, but there is some reason for thinking that the two latter may not have developed until somewhat later. The Hawkesbury Lake was essentially the same sheet of water as that in which the Upper Coal Measures were deposited, although for a time somewhat restricted in size, particularly on its northern margin; in this lake were deposited in succession the Narrabeen, Hawkesbury, and Wianamatta beds, with a maximum thickness of about 3,000 feet. As shallow-water conditions of deposition are in evidence, more or less, throughout all these beds, the lake-bottom must have been slowly subsiding.

The other two lakes mentioned were in reality parts of an extensive sheet of fresh water which covered large portions of southern Queensland and northern New South Wales, and which, perhaps, extended into South Australia. Parts of this lake became from time to time vast shallow swamps, in which grew the vegetation from which the Triassic coal seams were formed. The great thickness and the nature of the

sediments deposited shows that here, too, a slow subsidence was taking place, while the coal-seams indicate that the subsidence was of an intermittent nature, each coal-seam marking a period of comparative rest in the downward movement.

In the waters of these lakes fish abounded, while on the adjacent shores lived the large amphibia, which preyed upon them. Small Pelecypods (*Unio*) and Crustacea also inhabited the lakes and river waters. The surrounding country was clothed with a luxuriant vegetation; Cycads and Conifers flourished upon the uplands, while the marshes and swamps supported a dense growth of ferns and horse-tails. The great terrestrial and flying reptiles, which were such a characteristic feature of the life of other continents at this time, do not appear to have found their way into Australia.

CHAPTER XII.

THE CRETACEOUS PERIOD.

STRATA of this age occur over an extensive area in the northern and north-western parts of New South Wales—an area of upwards of 70,000 square miles. They are not known to occur in any other part of the State. No detailed geological surveys have been made of this area, consequently information regarding the Cretaceous formation is somewhat limited. As these Cretaceous strata are continuous with those of the same period in the adjoining States of Queensland and South Australia, the information gathered from these localities will be made use of to supplement that which has been obtained from New South Wales.

The Cretaceous formation of Australia has been subdivided as follows:—

- A. The Upper Cretaceous or Desert Sandstone Formation.
- B. The Lower Cretaceous or Rolling Downs Formation.

The Rolling Downs Formation.—Although this formation has been met with in sinking wells and bore-holes in New South Wales, no surface outcrops have yet been discovered. In Queensland, however, outcrops occur over extensive areas, particularly in that part of the southern portion of the State known

as the Rolling Downs. The surface here consists of gently undulating plains, or rolling downs as they are called, cut out of strata of Cretaceous age; hence the name. The strata in this region consist of shales, sandstones, limestones, marls, and gypseous clays, mainly of marine origin, but including some fresh-water deposits containing plant remains and thin seams of coal. The basal beds of the series, which consist of very porous sandstones, are known as the Blythesdale Braestones, and have been referred to by the Queensland Geological Survey as the intake beds of their artesian-water basin. As already stated, no surface outcrops of Lower Cretaceous strata have yet been met with in New South Wales, but considerable thicknesses have been passed through in sinking artesian wells. The Wallon bore, in the Moree district, passed through a thickness of 1,500 feet of these beds, consisting mainly of marine shales, sandstones, and limestones. The bore-hole at Buleroi, 60 miles to the south-west, passed through similar strata 620 feet in thickness. In both cases the Cretaceous strata were met with only a few feet from the surface, being covered and hidden by a superficial deposit of Post-Tertiary age. At Yandama Station, in the Milparinka district, 450 miles west of Moree, strata containing marine fossils characteristic of this formation were met with in sinking shallow wells.

Small flows of artesian water have been obtained from some of these Lower Cretaceous Strata; but, as already explained, the main supplies in New South Wales are being obtained from the underlying Trias-

Jura rocks. So far as is known, no unconformity exists between the two formations in New South Wales, but in Queensland a very distinct unconformity is believed by the local geologists to exist along the eastern margin of the Cretaceous basin.

The Desert Sandstone Formation.—This gets its name from its occurrence in the desert regions of the interior of Australia. In New South Wales the formation outcrops extensively in the north-western part of the State, and consists of coarse sandstones, grits, conglomerates, and beds of a fine-grained white siliceous rock, resembling kaolin in appearance. The sandstones and grits are the lowest beds of the series, and are of marine origin. In many localities the sandstone has been altered into an intensely hard, brittle, porcellanous rock resembling quartzite. This alteration has been brought about by the introduction of secondary silica, possibly by the action of thermal springs. At some localities, notably at White Cliffs, there occur above the sandstone beds of a very fine-grained, soft, white rock, which in some places is almost devoid of alumina, and consists of nearly pure silica, although in other places as much as 25 per cent of alumina may be present. Doubtful determinations of Radiolaria and Diatoms have been made, suggesting the probability of the rock having an organic origin. The same stratum also contains numerous fossil marine shells, fragments of fossilised wood, and the bones of marine reptiles (Sauropterygia). A remarkable feature at White Cliffs is the occurrence in this bed of numerous water-worn

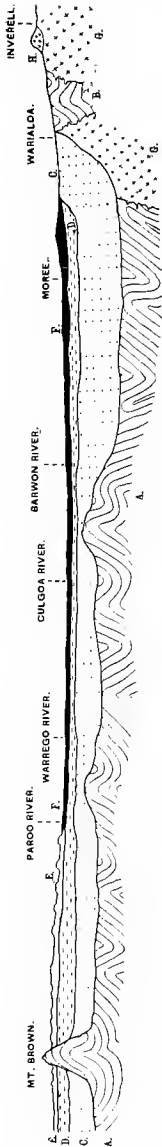


Fig. 74.

Section from Inverell to Mount Brown of the Cretaceous and Triassic Artesian Water-bearing Basin. (After Pittman.)

A = Silurian strata. B = (?) Carboniferous strata. C = Trias-Jura sandstones and shales (Artesian Series). D = Lower Cretaceous strata.
 E = Upper Cretaceous strata (Desert sandstones). F = Post-Tertiary Alluvium. H = Tertiary Basalt.

boulders of a fossiliferous Devonian quartzite, ranging up to 2 feet in diameter. The origin of these boulders has given rise to considerable discussion. The exceeding fineness of the sediments in which they are embedded precludes the possibility of transportation to their present position by running water. Transport by floating ice has been suggested; the boulders do not, however, show any glacial striae, and there is a total absence of any corroborative evidence. It has also been suggested that they may have been transported entangled in the roots of drifting trees. As Devonian quartzites outcrop about 20 miles to the westward, where part of the shore-line of the Cretaceous sea probably existed, and as fossil driftwood is common in the same bed as the boulders, there seems to be some probability of this being the correct explanation.

The Upper Cretaceous strata, which are always horizontal



Approximate area covered by the Lower Cretaceous Sea.

or nearly so, attain, both in the De Grey Ranges and at Mount Oxley (near Bourke), a thickness of about 500 feet. The formation, as a whole, has been extensively denuded since its deposition, so much so that, for the most part, mere isolated outliers remain of what was at one time a much more extensive formation. At Mount Brown, at Tibooburra, and near Milparinka, the basal conglomerates of the Cretaceous, where they dip away from the Lower Palæozoic strata, are auriferous. The gold has, no doubt, been derived from reefs traversing these Palæozoic strata, and concentrated in the Cretaceous gravels during the time they were being deposited.

At White Cliffs in the Wilcannia district, and at Lightning Ridge, near Walgett, precious opal occurs in the Upper Cretaceous rocks. It is of secondary origin, and occurs as irregular veins and patches in the white siliceous rock already referred to. At the former locality it is quite common to find marine shells, reptilian bones, and fragments of fossil-wood wholly or partly replaced by precious opal. The quality of the opal obtained is equal if not superior to that obtained in any other part of the world, and the value of the production to date exceeds £1,350,000 sterling.

The Upper Cretaceous strata in New South Wales, so far as is known, are conformable with the underlying Lower Cretaceous.

Cretaceous Life.—The Cretaceous flora is represented in New South Wales collections by coniferous wood only. In the De Grey Ranges a grove of fossil

tree-stumps occurs in the Desert Sandstone formation; these are standing in the position of growth, the larger ones having a diameter of about 4 feet. They must have been covered by the Cretaceous sediments while still erect, become petrified by infiltration of silica, and been re-exposed since by weathering. The occurrence of driftwood in some of the marine beds is not uncommon. In Queensland occasional thin seams of coal occur both in the upper and lower beds, and the fossil leaves of a considerable number of genera of dicotyledonous plants have been obtained from fresh-water beds in the same State. There is considerable probability, however, that these leaf beds are of Tertiary age.

With regard to the fauna, so little collecting has been done from the New South Wales strata that it will be more satisfactory to refer to the Cretaceous fauna of Australia as a whole. The invertebrate fauna, so far as we know it, consists dominantly of mollusca. Of these, the Pelecyopoda are particularly numerous; fifty genera and over 100 species have already been described. The Cephalopoda are also abundant, and with regard to size dominated all the other invertebrates. Specimens of *Crioceras* have been obtained in Queensland which range up to 2 feet or more in diameter. The genera *Ammonites* and *Belemnites* are abundantly represented. Gastropods are only sparingly represented. Foraminifera are abundant, but no beds of chalk are known to exist. Crinoids, echinoids, and sponges do not appear to have been abundant, while reef-building corals are

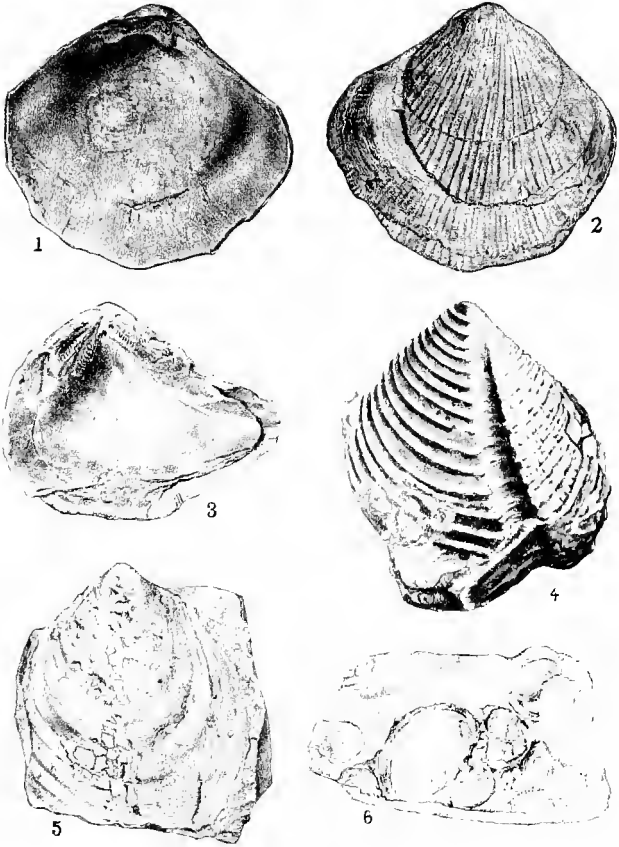


Fig. 76.

Cretaceous Pelecypoda.

- 1-2. *Macrocyella Burcklyi*. 3. *Trigonia usuta*. 4. *Trigonia Moorei*.
 5. *Inoceramus*, Sp. 6. *Ancella Hughesensis*.

totally absent. The vertebrates were represented by fish and reptiles. The latter belong to the two great cosmopolitan groups—the Sauropterygia and the Ichthyopterygia—and appear to have been numerous. The great terrestrial and flying reptiles, so abundant in the Northern Hemisphere at this time, were absent; at any rate none of their remains have yet been found.

LIST OF THE MORE IMPORTANT AUSTRALIAN
CRETACEOUS FOSSILS.

PLANTÆ:—Coniferous Wood.

FORAMINIFERA:—*Lagena*, *Nodosaria*, *Reophax*,
Cristellaria, *Haplophragmium*, *Polymorphina*.

SPONGIDA:—*Purisiphonia*.

CRINOIDEA:—*Isocrinus*,* *Pentacrinus*.

ECHINOIDEA:—*Micraster*.

VERMES:—*Serpula*.

BRACHIOPODA:—*Discina*, *Lingula*, *Rhynchonella*,
Terebratula.

PELECYPODA:—*Aucella**, *Corimya**, *Cucullæa**,
*Cyrenopsis**, *Glycimeris**, *Inoceramus**, *Lima*, *Mac-*
*coyella**, *Modiola**, *Mytilus*, *Nucula*, *Ostrea*, *Pecten*,
*Pseudavicula**, *Tellina**, *Trigonia**.

GASTEROPODA:—*Natica*, &c.

CEPHALOPODA:—*Belemnites**, *Ammonites*, *Ancylo-*
*ceras**, *Crioceras*, *Hamites*, *Haploceras**, *Nautilus*,
Scaphites.

PISCES:—*Belonostomus*, *Lamna*, &c.

REPTILIA:—*Cimoliosaurus**, *Agrosaurus*, *Ichthyo-*
saurus, *Notochelone*.

NOTE.—The genera marked with an asterisk have been found in New South Wales.

SUMMARY.

The subsidence which had been taking place during the deposition of the Trias-Jura fresh-water beds in western New South Wales and Queensland finally resulted in an invasion of the sea from the north, which, at the beginning of the Cretaceous Period, submerged the greater part of Queensland, a considerable part of Central Australia, and the north-western part of New South Wales (see map), and converted the whole of this area into a vast epicontinental sea. This subsidence continued intermittently throughout the Lower Cretaceous to an extent of at least 1,500 feet, allowing for the deposition of the Rolling Downs formation, all the strata of which show more or less evidence of shallow-water conditions of deposition. The existence of fresh-water beds and thin seams of coal indicate that parts of this Cretaceous sea were from time to time temporarily cut off from the main body and converted into swamps, in which a luxuriant vegetation flourished.

The unconformity which exists in some parts of Queensland between the Rolling Downs Formation and the Desert Sandstone Series shows that crustal movements took place after the deposition of the former, which brought about a temporary retreat of the sea—at least over the eastern part of the Cretaceous area. Renewed subsidence followed during the Upper Cretaceous, and a re-advance of the sea took place which transgressed in many places even

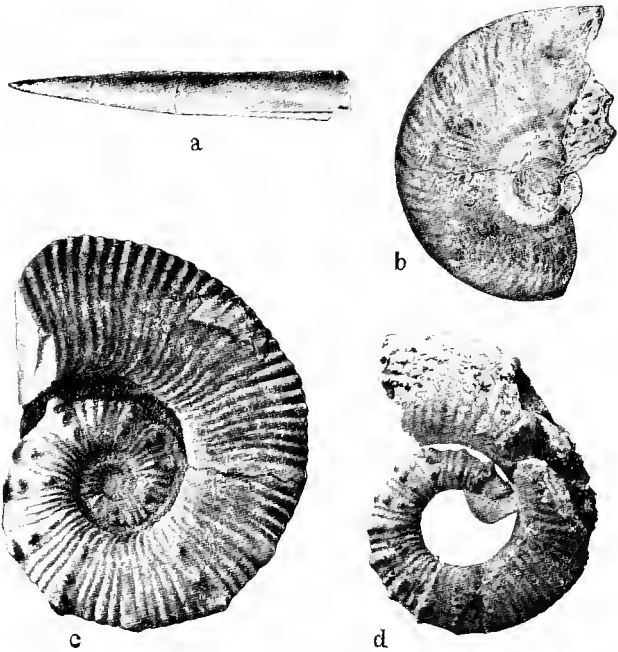


Fig. 77.

Cretaceous Cephalopoda.

- a. *Belemaites osts.* b. *Ammonites (Haploceras) Daintrei.*
c-d. *Crioceras Jucki.*

beyond the limits of the Lower Cretaceous sea. The marine fauna of the Upper Cretaceous appears to have been essentially the same as that of the Lower; this, together with the fact that in other parts of the area the two series are apparently conformable, may be taken to indicate that the retreat of the sea did not affect the whole area, and that the progress of life continued uninterruptedly throughout the period.

CHAPTER XIII.

THE TERTIARY PERIOD.

THE uplift which closed the Cretaceous Period converted the whole of existing New South Wales into dry land, and no part of it, excepting a limited area in the south-western corner, has since been beneath the sea. Tertiary marine strata are, therefore, excepting in the small area mentioned, absent in this State. There is also no evidence for the existence of any large Tertiary lakes, as lacustrine deposits of any importance are not known to occur; the only other Tertiary formations found are alluvial deposits (formed along the Tertiary river channels), lava flows, and tuffs. This comparative failure of the geological formations of New South Wales to provide a record of its Tertiary history is, however, compensated for to a large extent by the evidence obtained from a study of the development of its present topography.

Such Tertiary formations as occur may, from the point of view of their origin, be subdivided as follows:—

- (A) The Eocene (?Oligocene) Marine Strata.
- (B) The Fluvatile Deposits.
- (C) The Diatomaceous Earth Deposits.
- (D) The Volcanic Formations.

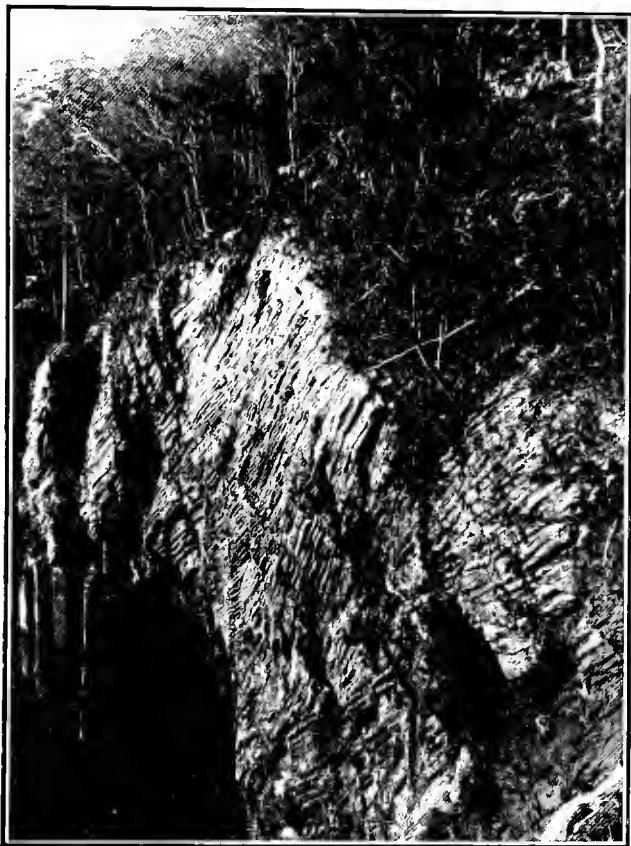


Fig. 78.

Tertiary Basalt Flow (Newer Basalt), Guy Fawkes, New England, New South Wales.

A.—THE MARINE STRATA.

These occur in the south-western part of the State, along the lower courses of the Murray and Darling Rivers; they consist of calcareous sandstones and shales containing marine fossils. They are concealed, for the most part, by more recent superficial deposits, but outcrop in places in the banks of the above-mentioned streams. A bore put down at Arumpo proved these beds to be at least 650 feet in thickness, as at this depth a characteristic Eocene Pelecypod (*Trigonia semiundulata*) was obtained. At Tareena and Mindarie similar beds have yielded abundant marine fossil shells, including various species of *Cucullæa*, *Crassatella*, *Trigonia*, *Cardita*, *Ostrea*, *Fusus*, *Voluta*, *Turritella*, and *Cerithium*. This marine fauna shows a commingling of species which in other parts of Australia are considered to belong to distinct Eocene and Miocene faunas. These beds are apparently co-extensive with marine strata in the adjoining States of Victoria and South Australia, which are by the geologists of those States referred to the Eocene (?Oligocene) Period. Their presence shows that the subsidence which affected the southern part of Australia at the beginning of the Tertiary Period formed a large embayment, whose extent is indicated in the map shown in Fig. 79. This transgression of the sea appears to have come to an end, so far as New South Wales was concerned, by the beginning of the Miocene Period.

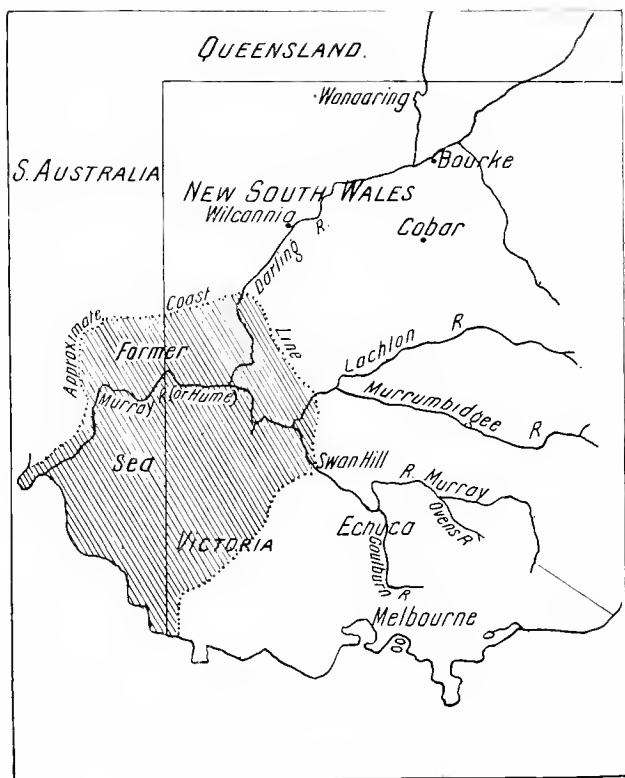


Fig. 79.

Map of the south-western part of New South Wales, showing the probable area covered by the sea in the early part of the Tertiary Period. (After Gregory.)

B.—THE FLUVIATILE DEPOSITS.

At many places in New South Wales old river channels are found buried between deposits of alluvium and sheets of basalt. In these channels are found beds of fine and coarse river-gravel, clay, sand, and in some few cases beds of lignite; the coarse gravels usually occur at the base of the deposit, and in many cases contain gold, tin-stone, gem-stones, &c. These buried gravels are known to the miners as "shallow leads" and "deep leads." The former may be defined as the alluvial deposits occurring along existing stream channels; the latter as a stream channel whose alluvial contents are buried beneath a capping of alluvium or lava (or both). In some cases, as at Kiandra and Bathurst, the old river channel, with its gravel and basalt capping, is on top of a hill 500 or 600 feet above the level of the present day tableland. These have yielded no recognisable fossil plants, and are probably of early Tertiary age; the basalt flows which cover and protect them are believed to be the equivalent of the "older basalt" of Victoria. These leads are provisionally referred to the Lower Tertiary (Eocene Period). In other cases, as at Forest Reefs and Gulgong, the old channels lie beneath the surface of the tableland, and may be below the level of the adjacent present day stream channels. Some of these contain numerous fossil leaves and fruits derived from a flora which, in its general character, was similar to the present day coastal brush vegetation. These leads are pro-

visionally referred to the Upper Tertiary (Pliocene Period).

(a) *The Lower Tertiary Leads.*

The Kiandra Lead.—This occurs on top of a hill adjacent to the town of Kiandra; the section in Fig. 80 shows it as exposed in the face of New Chum Hill. The materials forming this deposit are as follows (in descending order):—

Columnar basalt	..	..	..	11 feet
Earthy lignite	..	..	..	8 ..
Yellow and red sands and clays	..			35 ..
Lignite (containing tree-stems)	..			8 ..
Red and yellow clay	..	..	..	8 ..
Coarse sandy layers	..	..	..	45 ..
Red and yellow clay	..	..	..	6 ..
Lignite and black shales (containing plant remains)	..	..	..	25 ..
Earthy lignite	..	..	..	4 ..
Sand	..	..	..	3 ..
Auriferous wash	..	..	..	14 ..

This material lies in a well-defined rock channel up to 10 chains in width, and has been traced for a distance of about 20 miles; there can be no doubt that it is an old river channel. This deep lead has been cut across in several places by the present day streams, thus exposing good sections of it in their valley walls.

The Bathurst Lead.—This occurs on the top of the Bald Hills, adjacent to the town of Bathurst; the basalt capping has a thickness of about 200 feet, and almost directly overlies the quartz pebble wash.

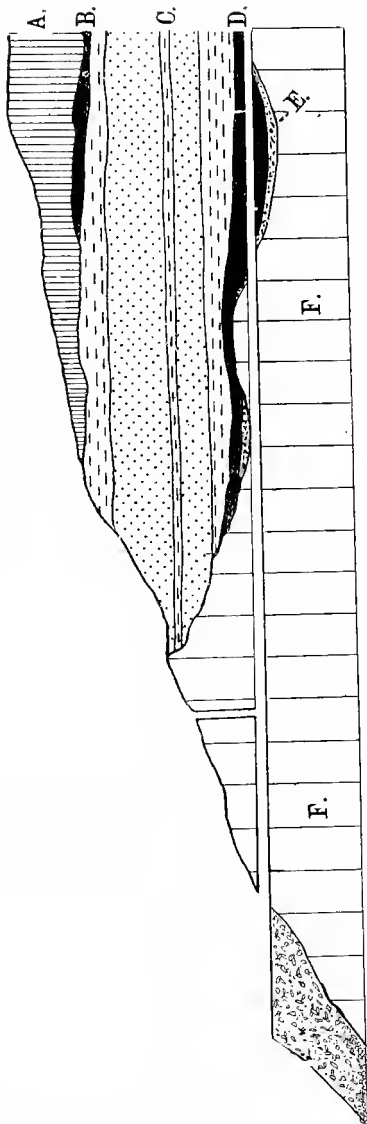


Fig. 80.

Section of the Kiandra Lead. (Andrews.)

A=Columnar Basalt. B=Beds of Sand and Clay. D=Lignite. E=Auriferous Wash 2 to 5 feet thick.
 F=Schistose Slates.

Between the two, on the north side of the hill, there is a deposit of white clay about 10 to 12 feet in thickness. The only fossils recorded from this lead are fragments of silicified wood. The bed of this old river channel is about 550 feet above that of the present day Macquarie River.

(b) *Upper Tertiary Leads.*

Vegetable Creek Leads.—These are in nearly all cases covered by basalt; in some places two distinct flows occur, separated by a small thickness of sand and clay. The Hume Lead at the Wesley Mine gave the following section:—

Red sandy soil	..	10	feet in thickness
Basalt	.. ..	8½	..
Tuff and scoriæ	.. ..	5½	..
Basalt flow	.. ..	21½	..
Do.	.. ..	73	..
Sands and clays	.. ..	22	..
Stanniferous gravels		3½	..

All the leads in this district are stanniferous (tin-bearing), the tin occurring in the form of water-worn grains of oxide of tin (cassiterite). Fossil plants are not uncommon in them, and include varieties of beech, oak, banksia, grevillea, laurel, and eucalyptus.

Many of the leads on the New England tableland, besides being stanniferous, contain gem-stones, such as diamond, sapphire, zircon, topaz, &c.

The Leads of the Parkes-Forbes District.—The leads of this district include both shallow and deep

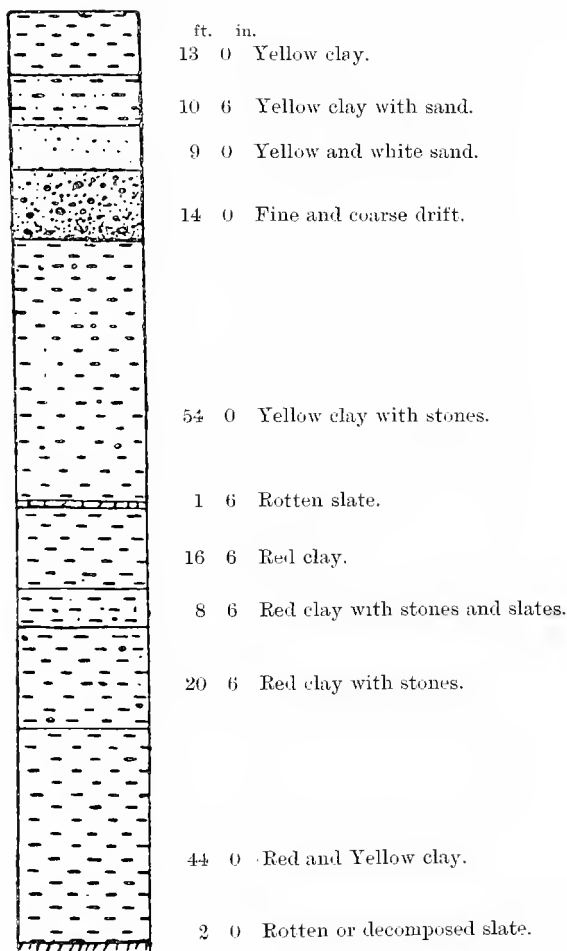


Fig. 81.

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Section of one of the "Deep Leads" at Forbes, New South Wales. (Andrews.)

leads, the former in many instances merging down stream into the latter. They are auriferous, the gold occurring (a) along the gutters of the main channels, and associated with the coarser stream deposits; (b) along the rim rocks or the sides of the buried stream channel; (c) in various irregularly arranged patches of coarse stream material situated above the older and deeper buried stream channels. In Fig. 81 is a section of a bore-hole put down through one of these alluvial deposits. These leads, unlike those in many other parts of the State, are not capped with basalt. Mr. E. C. Andrews, in his report on the Parkes-Forbes goldfield, gives the following history of the formation of these deposits:—

“(1) The land was raised, and a series of ‘valley in valley’ forms were excavated by the Lachlan tributaries. Along the steep channel bottoms gold was deposited by the rapid streams, for during the process of wearing the country down the lodes contained therein were also broken down, and their auriferous contents washed down and lodged in the channels of these old streams.

“(2) After the formation of these rock channels the land sank, and the rock-bound watercourses, instead of being deepened, were at this stage gradually filled up. The gold contents became poorer in these upper alluvial deposits; firstly, because the gold reefs were being buried in part; secondly, because the streams at this stage had not the power to carry the coarser gold as far as formerly; and, thirdly, because the gold was distributed through a vast width of

alluvial debris, instead of being concentrated near the bottom of a narrow gutter.

“(3) After the filling of the well-defined channels, the alluvial began to overflow the rock rims of these old watercourses, and to bury the lower portion of the main Lachlan valley. The streams at this stage ran in no well-defined channels, except locally, and gold was naturally jiggged and deposited upon the channel sides and also bottoms.

“(4) The land to the east of Forbes appears to have risen considerably at this stage, and heavy masses of coarse drift were laid down upon the clay and sand beds by swiftly flowing streams. As the strength of the stream decreased, the black soil plains were deposited in turn upon the coarse drift.”

The Gulgong Leads.—The alluvial deposits in these leads range from a few feet up to 200 feet or more in thickness, and are covered in some cases by basalt flows ranging up to 130 feet in thickness. These leads were very rich in gold, and in seven years (1869-1876) produced about 16 tons of this metal; the gold was derived from the denudation of the reefs in the surrounding Silurian strata. In these deposits abundant fossil leaves and fruits were obtained, as well as the bones of marsupials, some of which belonged to extinct species of large size.

The Forest Reefs Leads.—These occur beneath the basalt flows which form the capping of the tableland in the Orange district. They are similar to the Gulgong leads, and contain fossil fruits and leaves; they, too, are auriferous.

C.—THE DIATOMACEOUS EARTH DEPOSITS.

These occur at widely distant localities, such as Cooma, Canobolas Mountains, Warrumbungle Mountains, Barraba, Wyralla (Richmond River), &c. The deposits are in no case very extensive, and appear to have resulted from the accumulation of the frustules of diatoms and the spicules of sponges in small fresh-water lakes and lagoons. Nearly all these deposits are associated with Tertiary igneous rocks, those at the Warrumbungle Mountains being interstratified with trachytic lavas and tuffs. The following are analyses of material from some of these deposits, from which it will be seen that the diatomaceous earth is of good quality:—

	Cooma.	Barraba.	Warrumbungle. Mountains	Wyralla.
SiO ₂	81·64	80·56	82·62	86·01
Fe ₂ O ₃	0·40	1·77	5·20	2·83
Al ₂ O ₃	3·20	4·15	9·53	Not deter- mined.
CaCO ₃	1·50	0·31	0·70	do.
MgCO ₃	2·16	0·21	10·96	5·48
H ₂ O	10·95	12·84		

The diatoms which they contain belong mainly to the genus *Melosira*, and with these are associated the spicules of a fresh-water sponge (*Spongilla*). Impressions of the leaves of dicotyledonous plants and of fern fronds (*Pteris*) are frequently found in these deposits.

D.—THE VOLCANIC DEPOSITS.

Three distinct volcanic epochs seem to have occurred in New South Wales in the Tertiary period; two of these were productive of basaltic lavas only, but the third and latest produced a most interesting series of alkaline lavas and tuffs. The actual geological ages of these volcanic epochs will be discussed later; they may be referred to as follow:—

The Alkaline Lavas and Tuffs.

The Newer or Plateau Basalts.

The Older Basalts.

1. *The Older Basalts.*—These survive as cappings on some of the residuals, which rise in the form of isolated hills (Monadnocks), or long narrow ridges, above the surface of the great East-Australian Tertiary peneplain. River gravels underlie these basalt flows at many localities. The basalt capping at Kiandra lead, as shown in figure in the previous chapter, belongs to this period, as also does that capping the Bald Hills near Bathurst (Fig. 82); the basalt cappings on some of the peaks rising above the level of the surface of the Blue Mountain tableland also probably belong to this epoch. These basalts flowed down the valleys which occurred on the surface of a (?) Cretaceous peneplain, thus covering the river gravels. How extensive these flows were it is now impossible to estimate, as what we see to-day are mere isolated remnants both of the basalt and the peneplain upon which it rested.

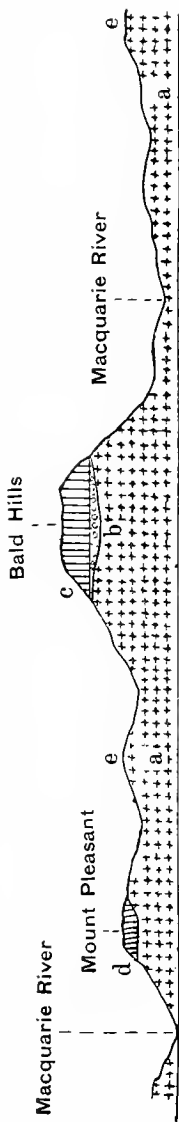


Fig. 82.

Section Across the Bald Hills, Bathurst, New South Wales.

- a. Granite. b. Lower Tertiary river gravels. c. Basalt flow (the Older Basalts). d. Basalt flow (the Newer Basalts).
 e. Level of the Great East Australian Peniclinium.

The Newer Basalts (Plateau Basalts).—These occur as extensive sheets (flows), resting in many places upon the surfaces of the tablelands of New South Wales. This series has its greatest development on the New England tablelands, covering there many hundreds of square miles in the neighbourhood of Inverell, Glen Innes, Armidale, Walcha, and other localities. On the Central tableland they have a considerable development in the Orange-Blayney and Oberon districts, while on the southern tableland they are extensively developed between Cooma and Bombala. Many of these basalt flows appear to have resulted from fissure eruptions, as we seldom find anything in the nature of volcanic cones in the districts in which they occur, while associated tuffs are rare. In the Vegetable Creek district the flows range up to 300 feet in thickness, and here beds of tuffs ranging up to 40 feet in thickness do occur;

these latter are now much altered, and are known as laterite.

These basalts, with regard to their distribution, are practically confined to the tableland regions, although poured out before the tablelands themselves were uplifted. There appears, therefore, to have been some causal relation between the vulcanicity and the later epeirogenic uplift.

The Alkaline Lavas and Tuffs.—These are widespread in their distribution, like the basalts, but occur in the form of groups of extinct volcanic cones, covering in each case a very limited area. The Canobolas Mountains, near Orange, the Warrumbungle Mountains, near Coonabarabran, and the Nandewar Mountains, near Inverell, are the best known of these occurrences. The Canobolas Mountains cover an area of about 10 miles square on the western edge of the Central tableland, near Orange; the tableland here has an elevation of about 3,000 feet, and the volcanic series of the Canobolas Mountains rests upon the surface of this tableland, and rises to a maximum altitude of 4,610 feet, *i.e.*, about 1,600 feet above the tableland level.

The first eruption brought to the surface a series of highly acid and alkaline lavas called Comendites (alkaline trachytic rhyolites) and Alkaline Quartz Trachytes; these built up a number of steep lava cones. The next series of eruptions produced alkaline trachytes and extensive beds of tuff of somewhat similar composition; while still later eruptions pro-

duced alkaline andesites of a somewhat basic type. The order of eruption was as follows:—

1. Comendites and quartz trachytes.
2. Alkaline phonolitic trachytes.
3. Andesites.

The sequence shows increasing basicity.

The alkaline rocks of the Warrumbungle and Nandewar Mountains closely resemble those of the Canobolas Mountains both in chemical composition and lithological characters, while the sequence of eruption was the same in all these localities. Analyses of these rocks are given on page 248.

THE TERTIARY FLORA.

As has already been mentioned, numerous fossil fruits and leaves have been obtained from some of the Tertiary leads. Those at Forest Reefs and Gulgong, in particular, have yielded a large number of fossil fruits, which include the genera *Plesiocapparis*, *Spondylostrobus*, *Penteunc*, as well as numerous others.

A large number of fossil dicotyledonous leaves have been obtained from the deep leads at Gunning, Forest Reefs, Emmaville, &c., and have been referred to such genera as *Alnus*, *Quercus* (Oak), *Fagus* (Beech), *Cinnamomum*, *Laurus* (Laurel), *Magnolia*, *Bombar*, *Pittosporum*, *Eucalyptus*, *Banksia*, and *Grevillea*. This flora has been described as containing representatives of the existing floras of many parts of the world, and entirely different to that now occurring in Australia. Both the generalisation and

some of the generic and specific determinations upon which it is based are open to serious question. It has been shown that it is unnecessary to seek outside Australia for the types of our Tertiary fossil plants, as they are to be found in the luxurious flora now confined to strips and patches along the coast, where there is a warm climate and an abundant rainfall. The Tertiary representatives of this present day coastal "brush" flora had a very wide distribution, occurring from Tasmania to Queensland, and as far west, at least, as Orange. These regions, some parts of which are now relatively cold, and other parts relatively dry, must have had a warmer and moister climate during the Tertiary Period in order to have supported such a vegetation. It will be shown in the next chapter that the present tableland regions of East Australia were preceded by an extensive peneplain elevated but little above sea-level, the only highlands then existing being isolated hills and long narrow ridges, few, if any, of which reached an elevation of 1,000 feet. Under such topographical conditions this region would have, it is considered, a more or less uniformly warm and moist climate which would be capable of supporting such a "brush" vegetation as appears to have covered it in Upper Tertiary times. The Tertiary flora, then, while differing to a considerable extent from that of the present tableland regions, with their relatively cold climate, and of the western slopes and plains with their hot and semi-arid conditions, was, taken as a whole, not very different from our present day coastal "brush" flora.

THE TERTIARY AND PLEISTOCENE LAND FAUNAS.

The dominant group of land animals during this period was, as is the case at the present day, that group of the Mammalia known as the Marsupialia; the Monotremes were also well represented, but none of the higher mammals (Placental Mammals) were present. The following is a list of the more important land animals of the Tertiary Period:—

VERTEBRATA ...	}	Marsupialia	}	<i>Diprotodon</i>
				<i>Nototherium</i>
				<i>Phascolomys</i>
				<i>Phascalomys</i> (Wombat)
				<i>Thylacoleo</i>
				<i>Thylacinus</i> (Tasmanian Tiger)
				<i>Sarcophilus</i> (Tasmanian Devil)
				<i>Macropus</i> (Kangaroo)
				<i>Halmaturus</i> (Wallaby)
				Monotremes	}	Echidna
<i>Ornithorhynchus</i> (Platypus)				
Aves (birds)		<i>Dromornis</i> , &c.		
Reptilia	}	<i>Megalania</i> (Giant Lizard)		
		<i>Chelodina</i>		
		<i>Meiolania</i> (Turtle)		
INVERTEBRATA	}	Pelecypoda	<i>Unio</i>	
		Spongia	<i>Spongilla</i>	

It is still uncertain whether all the vertebrates listed above had already appeared in the Tertiary Period. Those found in the Gulgong deep leads (*Diprotodon*, *Meiolania*, *Echidna*, *Ornithorhynchus*) are undoubtedly of Tertiary Age, but the others have never yet been found in undoubted Tertiary deposits, although it is probable that most, if not all, of them had already appeared in the Tertiary Period.

Some of the genera listed above are now extinct, and those which survive are represented, for the most



Fig 83.

Diprotodon australis, restored. (Angas.)

The largest of the fossil marsupials.

part, by different species. As compared with their present-day representatives, the Tertiary vertebrates were characterised by their larger size; not that small species did not exist, but that many which then lived were larger than any existing to-day. The largest of all was the genus *Diprotodon*, a marsupial as large as

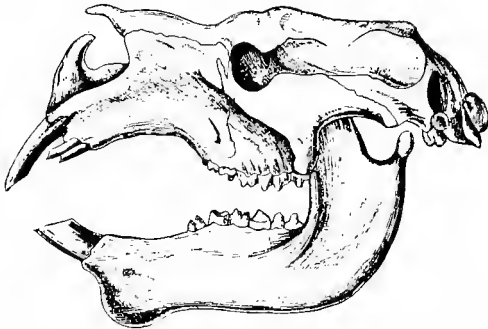


Fig. 84.

Skull of *Diprotodon australis*. (After Owen).

a rhinoceros, which walked on all-fours; its skull in some cases was over a yard in length. This huge extinct marsupial lived in large numbers even in the far western parts of the State, where, under existing conditions, they would die of starvation and thirst. This supports the evidence given by the Tertiary plants that the climate was at that time moister than at present, and that the land was clothed with a luxuriant vegetation.

Nototherium was also of large size, quadrupedal in habit, and resembled in general appearance a large

tapir. The wombats (*Phascalomys*) were much larger than their present day descendants, as were also the kangaroos (*Macropus*) and wallabies (*Halmaturus*). Carnivorous marsupials, which do not now exist on

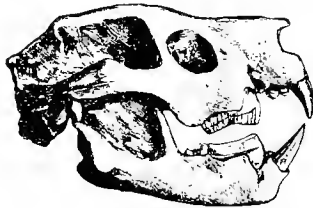


Fig. 85.

Skull of *Thylacoleo carnifex*. (After Owen).

the mainland of Australia, were represented by the two living Tasmanian genera *Thylacinus* (Tasmanian tiger) and *Sarcophilus* (Tasmanian Devil), but here again by larger species. The disappearance of these two genera from the mainland was, possibly, due to the advent of the dingo (*Canis Dingo*), which may have been introduced into Australia by the aborigines. *Thylacoleo* (Marsupial Lion) is another fossil marsupial, said to have been carnivorous in habit, but there is considerable difference of opinion upon this point.

Genyornis and *Dromornis*, the largest of the Tertiary birds, somewhat resembled the present-day Emu, but were larger. The present-day Monotremes—*Echidna* and *Ornithorhynchus*—were also represented by larger species, while the Reptilia included lizards and turtles.

Many of the Tertiary vertebrates which are now extinct possibly still lingered on into the early part of the Pleistocene Period, and their extinction, particularly in the case of the larger herbivorous forms, probably resulted directly or indirectly from the climatic changes which followed the extensive uplift that closed the Tertiary Period.

The Marine Fauna.—A list of the more important genera found in New South Wales has already been given on page 189. All the genera still survive in our present seas, although the majority of the species are extinct. As but little collecting has been done in the marine Eocene beds of New South Wales, a list of the more characteristic Lower Tertiary marine fossils occurring in the adjoining States of Victoria and South Australia is given on page 215. These will give a better idea of the general characteristics of this marine fauna, which consisted dominantly of Pelecypods and Gasteropods.

ECONOMIC IMPORTANCE OF THE TERTIARY FORMATIONS.

As has already been pointed out, many of the Tertiary fluviatile deposits contain substances of economic value: these include gold, platinum, tin-stone, and precious stones. Of the total gold (value £60,000,000) and tin (value £8,750,000) produced in New South Wales to date, considerably more than one-half has probably been obtained from these alluvial deposits. The Tertiary basalts have, by their decomposition, produced much of the best agricultural land in the State, and thus indirectly added to

the national wealth to a greater extent even than the gold and tin-bearing alluvial deposits.

THE DEVELOPMENT OF THE PRESENT TOPOGRAPHY.

The information regarding the history of the Tertiary Period in New South Wales, obtained from a study of its Tertiary formations, is very meagre, and it is desirable to supplement it as far as possible from other sources. A study of its present topography supplies much important information. No part of the State, except one very small area, has been beneath the sea since the Cretaceous Period, while the major portion has not been beneath the sea since the end of the Palæozoic era. Considerable areas (see Fig. 73), however, were covered by fresh-water lakes in the Trias-Jura Period. The present topographical features, therefore, have been in course of development since as far back, at least, as the Trias-Jura Period over all parts of the State, except the area covered by the Cretaceous sediments in the northern and north-western regions and the small area covered with Eocene marine strata in the south-western corner.

The surfaces of the various tablelands forming the highlands of New South Wales and of the low plateaux of the central-western areas are all parts of one and the same peneplain, cut indiscriminately out of strata varying from Pre-Cambrian to Trias-Jura in age. Whether the same feature extends into the Cretaceous area of the north-west is not known to the author, but it is thought that it probably does. This peneplain was uplifted at the close of the Ter-

tiary Period to form the existing tablelands; it was probably developed during the Tertiary Period, although some geologists are of opinion that it may have been produced during the Cretaceous Period. As it occurs throughout the whole of Eastern Australia, the name "Great East-Australian Peneplain" would be an appropriate one for it, and will, therefore, be used here.

Resting upon the surface of this peneplain in many places are extensive sheets of basalt (the newer basalt); these lava flows were obviously poured out after the peneplain surface had been developed. They cover, in many localities, old river channels (deep leads), such as those at Gulgong and Forest Reefs, whose valleys, which seldom exceed 300 feet in depth, and their contained alluvial deposits are, of course, also younger than the peneplain. It is these leads which contain the fossil leaves and fruits referred to on page 202. The surface of the peneplain is not flat, but is traversed in most places by a network of broad, shallow, mature valleys, ranging from 150 to 300 feet in depth; these have been cut out of the basalts as well as out of the older rocks, and are, therefore, younger than the basalts.

Rising above the general level of the Great East-Australian Peneplain are numerous isolated hills and long narrow ridges. They consist, in some cases, of tilted palaeozoic strata; in others, of plutonic igneous rocks; while others, again, are made up of nearly horizontal Triassic strata. In any one district the highest of these residuals all rise to about the

same altitude above the peneplain level, showing that they are residuals of an older tableland, the surface of which was also a peneplain. This older peneplain was probably cut out during the Cretaceous Period. It will be convenient to refer to it as the Cretaceous Peneplain, it being understood, however, that the age assigned to it is provisional. On the Yass-Canberra tableland the residuals of the Cretaceous Peneplain rise to a height of from 600 to 850 feet above the level of the Great East-Australian Peneplain, indicating that the tableland which preceded the present one in this region had a minimum height of about 850 feet. Many of the residuals of the Cretaceous Peneplain are capped by basalt flows; these have been referred to on a previous page as the Older Basalts; the river gravels underlying them contain, as far as is known, no recognisable fossils.

The succession of events which produced these topographical features, with the ages provisionally assigned to them, may have been somewhat as follow:—

Cretaceous—

A cycle of erosion which produced the older peneplain, followed by an epeirogenic uplift, which converted the peneplain into a tableland, and ushered in the Tertiary Period.

Lower Tertiary—

- (a) Volcanic eruptions, which brought to the surface basalt flows—*the Older Basalts*.
- (b) A cycle of erosion, which produced the Great East-Australian Peneplain.



Fig. 86A.
The Great East-Australian Peneplain, near Canberra, showing Mount Ainslie, a residual of the
Cretaceous Peneplain.



Fig. 86B.
Federal Capital Site, Canberra, showing the Great East-Australian Peneplain.

Upper Tertiary—

- (a) A slight uplift, followed by renewed volcanic activity, with the pouring out of vast sheets of basaltic lavas—*the Newer or Plateau Basalts*.
- (b) Development of the shallow mature valleys now occurring on top of the tablelands.
- (c) Volcanic eruptions at several centres, which were productive of *The Alkaline Lavas*.

Kosciusko Epoch—

- (d) Great epeirogenic uplift, which produced the existing tablelands, and ushered in the Pleistocene Period. This uplift was accompanied by normal faulting and monoclinial folding on a large scale, with the subsequent production of Fault Blocks, Horsts, Senkungsfelder (Rift Valleys) and Fault Escarpments.

Pleistocene to Recent—

The existing cycle of erosion, during which the tablelands produced by the late Tertiary uplift have been partly dissected.

SUMMARY OF THE TERTIARY PERIOD.

The earth-movements which closed the Cretaceous Period brought about (1) a retreat of the epicontinental sea which had previously covered the north-western part of the State; (2) a transgression of the sea which covered a relatively small area in the south-western corner; (3) the conversion of nearly the whole of New South Wales into a tableland, which in the

eastern part ranged from 600 to perhaps 1,000 feet in altitude.

Very early in the Tertiary Period volcanic eruptions began, from which basaltic lava-flows poured down the then river valleys, covering up the layers of sand and gravel (and in some cases, lignite) which occurred in them (the Older Leads). These basalts are probably the equivalents of the "Older Volcanics" of Victoria, which are associated there with Lower Tertiary marine strata, and which also in some cases overlie lignite deposits. Owing to the absence of recognisable fossils in these older leads, nothing definite is known of the terrestrial fauna and flora of this time. Long continued erosion during the Lower Tertiary Epoch removed almost entirely the tablelands formed at the close of the Cretaceous Period, and cut out of it the Great East-Australian Peneplain.

A small uplift at the beginning of the Upper Tertiary Epoch brought about a retreat of the epicontinental sea which had previously covered part of the south-western region of New South Wales. This small uplift enabled the rivers to entrench themselves in their old valleys, and bring about the formation of the "Upper Tertiary Leads," in which are preserved abundant remains of the Upper Tertiary plants and land animals. A study of these fossils, as has already been shown, indicates that the whole of the State at this time enjoyed a warm, moist climate, and was clothed with a dense sub-tropical vegetation, very different to that which now covers much of it, but

similar to the present-day coastal "brush" vegetation. The dominant land animals then, as now, consisted mainly of marsupials, but included also monotremes, reptiles, large birds, &c.; all of these had representatives larger than any living to-day. The larger size of many of the Tertiary Vertebrata, the large numbers of them which seem to have inhabited what are now the more arid parts of the State, and the fact that some of these larger marsupials were apparently quite unfitted to travel long distances in search of food, suggests that a luxuriant vegetation existed at the time they lived, even in the far western parts of the State. A much more regular and more abundant rainfall must therefore during the Upper Tertiary period have existed over what are now the drier parts of the State; while, owing to the absence of high mountains and tablelands, the climate of the whole State must have been sub-tropical as well as moist. This latter fact is borne out by finding the leaves of sub-tropical plants in the Upper Tertiary Leads occurring on the high tablelands which now have a relatively cold climate.

Before the Upper Tertiary Epoch was far advanced, great sheets of basaltic lava (the newer basalts) were poured over the peneplain surface, particularly in the eastern part of the State, in most cases, apparently, from fissure eruptions; these buried many of the river channels, thus forming the Upper Tertiary Deep Leads, and preserving the fossil animals and plants which these river deposits contain.

This volcanic phase was followed by a considerable

period of erosion, during which the broad, shallow, mature valleys were cut both out of the basalts and the peneplain upon which they rest.

Immediately preceding the great uplift which closed this period active volcanoes broke out at several centres, from which highly alkaline lavas and tuffs were poured out, and which built up groups of volcanic cones such as the Canobolas, the Warrumbungle, and the Nandewar Mountains.

Close of the Tertiary Period—Kosciusko Epoch.—This was marked by an epeirogenic earth movement of considerable magnitude, as a result of which the whole of the eastern part of the State was uplifted so as to form the existing tablelands; it ranged in amount from 2,000 to 6,000 feet. This uplift was accompanied by extensive normal faulting and warping, some of the faults having a vertical throw of at least 3,000 feet. The more important and the greater number of these faults and warps strike approximately north and south, but east and west faults and warps also occur. The development of these faults produced a series of great fault blocks, the surface of each of which is part of the Great East-Australian Peneplain. In some localities—for example, at Cooma and at Jindabyne—relatively narrow fault blocks are bounded on either side by much higher blocks, thus forming “Rift Valleys” or Senkungsfelder. Two large areas in the eastern part of the State—viz., the area surrounding Sydney and that surrounding Grafton—lagged behind, were uplifted but little above sea-level, and now form relatively

depressed areas. These movements brought about considerable modification of the drainage systems and of the main divides. For the period of time during which these earth movements were taking place, the name Kosciusko Epoch has been suggested by Mr. E. C. Andrews.

The western parts of the State were also uplifted at this time, but to a much less extent, ranging up to 800 feet—in no case exceeding 1,000 feet.

LIST OF CHARACTERISTIC TERTIARY MARINE FOSSILS
OF S. AUSTRALIA AND VICTORIA.

ACTINOZOA.—*Flabellum*, *Placotrochus*, *Plesiastrea*.

ECHINOIDEA.—*Leiocidaris*, *Salenia*, *Clypeaster*,
Holaster, *Eupatangus*, *Louenia*.

POLYZOA.—*Adcona*, *Retepora*, *Cellepora*.

BRACHIOPODA.—*Terebratula*, *Waldheimia*.

PELECYPODA.—*Ostrea*, *Pecten*, *Hinnites*, *Lima*,
Spondylus, *Mytilus*, *Cucullra*, *Pectunculus*, *Trigonia*,
Crassatella, *Cardita*, *Cardium*, *Chione*.

GASTEROPODA.—*Triton*, *Fusus*, *Voluta*, *Pleurotoma*,
Conus, *Cypræa*, *Natica*, *Tunitella*, *Cerithium*,
Haliotus.

CEPHALOPODA.—*Aturia*.

VERTEBRATA (Pisces).—*Shark's Teeth* (*Charcharodon*).

CHAPTER XIV.

PLEISTOCENE PERIOD.

THE close of the Tertiary Period (Kosciusko Epoch) was marked by that great epeirogenic uplift referred to in the last chapter, which produced the existing tablelands. This uplift did not bring to light any of the marine deposits which must have been forming along the eastern coast during the Tertiary Period. It is probable, therefore, that the shore-line extended further to the east than it does now, and that the coastal strip of the Tertiary land subsided during the Kosciusko Epoch coincidently with or immediately after the uplifting of the tablelands, and was separated from them by a line of faulting and warping, corresponding approximately in position with the present shore-line.

The cycle of erosion initiated by the Kosciusko uplift is still in progress, and has not yet reached maturity. The streams, rejuvenated by the uplift, held their courses against the rising land, and have, for the most part, entrenched themselves in their old channels. They have cut deep gorges and valleys into the tablelands, but have only partly dissected them, the central parts of the tablelands being still more or less intact. The faulting and warping which accompanied the uplift did, however, produce some important modifications of the Tertiary drainage sys-



Fig. 87.
Lake Albina, Kosciusko Tableland, showing Glacial Topography.

tems—as, for example, the capture of a considerable part of the original watershed of the Snowy River by the Murrumbidgee River.

The Kosciusko uplift profoundly modified the Tertiary climate and the Tertiary fauna and flora. Where there had previously been level low-lying land, extending more or less over the whole State, there was now developed a continuous belt of great tablelands, 2,000-6,000 feet in altitude, paralleling the coast from Victoria to Queensland, and entirely cutting off the but-little-elevated western region (the Western Plains) from the coast. The eastern tablelands, owing to their greatly increased elevation, would of necessity develop a colder climate; the western regions, on the other hand, have developed a semi-arid climate, owing probably to the cutting off of the moisture-laden winds from the Pacific Ocean by the introduction of the great north and south tableland barrier.

The first important effect of the geographical and climatic changes was to modify profoundly the Tertiary flora. Plants like *Quercus*, *Fagus*, *Cinnamomum*, *Magnolia*, and *Laurus* died out, excepting in the moister warm coastal areas, while a much hardier vegetation, consisting predominantly of Eucalypts and Acacias, took their place. The genus *Eucalyptus* in particular marvellously adapted itself both to the colder climate of the high tablelands and the drier climate of the interior, and evolved a very large number of new species.

This modification of the Tertiary vegetation reflected adversely upon the vertebrate animals, bring-

ing about the extinction of many of the Tertiary genera and species, particularly those of large size, such as *Diprotodon*, *Nototherium*, &c., and the large Tertiary species of kangaroos, wallabies, and wombats.

PLEISTOCENE DEPOSITS.

The abrupt change in elevation in passing from the high eastern tableland to the low-lying western plains has resulted in the latter forming a base-level for the denudation of the former. The western rivers draining the tableland overflow their banks during flood-time, where they enter the western plains, and have formed extensive alluvial deposits on their flood-plains. Westwards the flood-plains of neighbouring rivers become co-extensive, forming great "Piedmont" plains, such as the "Blacksoil Plains" of the north-west, and the "Riverina Plains" of the south-west. These deposits range up to several hundreds of feet in thickness, representing the waste of the tablelands since the beginning of the Pleistocene Period, and are still being added to. Some of the shallow leads along the western margin of the tableland region probably also belong to this period.

East of the Main Divide denudation was the dominant feature during the Pleistocene Period, but alluvial deposits along the lower courses of some of the larger rivers, such as the Hunter and the Clarence, began their formation during this period.

THE GLACIAL EPOCH.

Australasia, in common with Europe and North America, had its "Glacial Epoch" during the Pleisto-



Fig. 88.
Lake Coofapatamba—A Moraine Lake.

cene Period. On the mainland of Australia the refrigeration of the climate was only of sufficient amount to produce glacial conditions over one very small area, viz., the Kosciusko tableland. This is the only surface of any extent in Australia which has an altitude of upwards of 5,500 feet—the downward limit of the ice-action in the Kosciusko region during this period. A few other points in the neighbouring parts of New South Wales and Victoria project above this level, but are too small in area to have afforded a gathering ground for snow and ice. Extensive areas in the highlands of Tasmania and New Zealand, however, supported large ice sheets and glaciers at this time.

The Kosciusko tableland affords evidence of two distinct ice invasions. The evidence for the older of these consists of—

- (1) U-shaped glaciated valleys.
- (2) Hanging valleys.
- (3) Truncated spurs.
- (4) General smoothing of rock surfaces.
- (5) Morainic material.
- (6) Alluvial flats, representing aggraded glacier lakes.

This visitation consisted of an ice-sheet extending over an area of from 80 to 100 square miles, and with a maximum thickness of not less than 1,000 feet. The downward limit of the ice appears to have been about 5,500 feet. During this time the snow-line must have been fully 3,000 feet lower than it is now,

which would mean a lowering of the present mean annual temperature by about 10° Fah.

Professor David has estimated that this ice-sheet existed from 100,000 to 200,000 years ago.

Still more recently, probably about 10,000 years ago, a second but less extensive glaciation took place in the same region. At this epoch a number of valley glaciers developed, ranging up to 500 feet in thickness, but not more than a mile or two in length. The evidences left by these valley glaciers consists of—

- (1) Lateral and Terminal Moraines,
- (2) Glacier Lakes,
- (3) Glacial Erratics,
- (4) Glaciated Pavements and Roches Moutonnés.

The glacier lakes include the Blue Lake, Lake Albina, and Lake Cootapatamba. The two latter are moraine lakes; but the first-named lies in a true rock basin, with a terminal moraine at its lower end.

RECENT EARTH MOVEMENTS.

A study of the physiography of the present coast affords abundant evidence of a recent subsidence having taken place. Similar evidence occurs along the whole coast of Eastern Australia. Such inlets as Port Jackson, Botany Bay, Broken Bay, and many others along the coast, are drowned river valleys, the amount of drowning indicating a subsidence of about 200 feet. Numerous coastal lakes and lagoons, such as Lake Illawarra, Tuggerah Lakes, Lake Macquarie, exist. These too are drowned valleys, which have more recently been cut off from the sea. Other fea-

tures of the shore-line, such as the continental islands (these are more numerous on the Queensland coast), the bold headlands, and the deep water inshore afford additional evidence of this subsidence.

These evidences of subsidence could, of course, have been produced by a positive rising of the sea-level. Every continent shows similar evidences of an apparent subsidence in Pleistocene times, and it has been suggested that the setting free of the vast quantities of water stored up on the surface of the land in the form of ice and snow during the glacial epoch would have caused a raising of the sea-level sufficient in amount to produce the apparent subsidence of the land shown.

Interesting evidence of a comparatively recent subsidence is given by a section revealed in the cutting of a canal at Shea's Creek, near Sydney. This section revealed the following beds:—

(a) Sandy peat	.. .. .	1 foot
(b) Blown sand with thin layers of peat	.. .. .	3 ..
(c) Marine sandy shales with Estuarine shells	.. .. .	2 ..
(d) Peaty loam with stumps of trees (<i>Eucalyptus botryoides</i>)	..	1 ..
(e) Estuarine clays with shells and stumps of trees <i>in situ</i>	..	9-10 ..
(f) Bed of peat with numerous stumps of trees <i>in situ</i> (submerged forest)	.. .. .	1-5 ..
(g) White sands	.. .. .	3 ..

A bore-hole put down in the vicinity showed the white sands at the bottom of the above section to be $8\frac{1}{2}$ feet thick, and below this was a bed of blue clay 12 feet in thickness and resting upon bedrock. In the horizon (*c*) was found part of the skeleton of a Dugong, a marine mammal now rarely seen south of the latitude of Brisbane, and at the same horizon two aboriginal tomahawks were found; another tomahawk was found on the horizon of the submerged forest at (*f*). The stumps of the trees were undoubtedly *in situ*; this particular eucalypt (*E. botryoides*) does not flourish below the level of high water mark. The horizon of the submerged forest (*f*) is 10 feet below low water mark. This section gives evidence of a subsidence of about 15 feet.

A closer study of the coast affords evidence of a still later movement of the earth's crust—one of uplift. This uplift was only of small amount, about 10-20 feet. In some of the more sheltered bays and estuaries the sea-bottom has been lifted a few feet above sea-level over limited areas. Islands produced by the previous subsidence have in this way been rejoined to the land, thus forming tied islands or tombolas.

Further evidence for this recent uplift is given by the "raised beaches" of the Hunter River delta, near West Maitland. Estuarine beds, containing marine shells, occur here at heights of as much as 15 feet above high-water mark—this is shown in the accompanying section. At Largs this estuarine deposit has yielded upwards of thirty species of living marine shells.

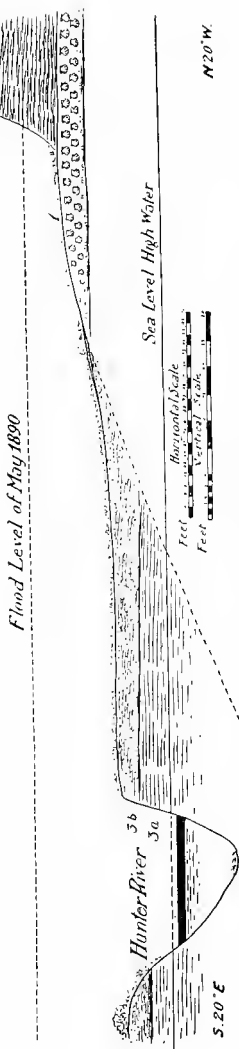


Fig. 89.

Section of the Raised Beach at Largs, near West Maitland. (David.)

1. Raised Beach, with marine shells.
2. Pleistocene alluvium.
3. Recent alluvium.

CHAPTER XV.

THE IGNEOUS ROCKS OF NEW SOUTH WALES.

FREQUENT reference has been made in previous chapters to the igneous rocks of the different geological periods; it will, perhaps, serve a useful purpose to summarise in this chapter our present knowledge of these igneous rocks.

The most satisfactory method of treating this branch of the Geology of New South Wales would be to consider the intrusive and volcanic rocks together and show their relationships from both a chronological and a petrological standpoint. So little work has been done in correlating these two groups of rocks, however, that the available information is too meagre to allow of this being satisfactorily done; each group, therefore, will be dealt with separately.

A.—INTRUSIVE ROCKS.

Very little systematic research work has yet been carried out with regard to the intrusive igneous rocks of this State, and our present knowledge, therefore, is so limited that broad generalisations are almost impossible; consequently many of the conclusions put forward here must be looked upon as being quite tentative. From the point of view of age, these rocks fall naturally into two groups (*a*) those of Palæozoic

Age (*b*) those of Cainozoic Age. During the Mesozoic Era both plutonic and volcanic activities appear to have been dormant.

(*a*) *Palaeozoic Intrusive Rocks*.—The intrusion of large plutonic masses of igneous rock during this era seems to have been definitely related to important crustal movements of the orogenic type; each mountain-making epoch appears to have been a time of plutonic activity. The most important of these epochs appears to have been (1) that which took place in pre-Cambrian times in the western part of the State; (2) that which closed the Devonian Period (the Kanimbla Epoch), when intrusions of granite and allied rocks took place on a grand scale; and (3) those which took place towards the end of the Palaeozoic Era in the north-eastern part of the State. That the earlier Palaeozoic mountain-making epochs had their plutonic intrusions is most probable, but at present we have but little knowledge of them. Granite intrusions of pre-Cambrian Age occur in the Barrier district in the far western part of New South Wales, and some of the gneisses which form part of the Metamorphic Series of this district are probably altered granites, and are also of pre-Cambrian age. Some of the hornblende and augite-porphyrites associated with the Ordovician strata appear to be intrusive and to be of pre-Silurian age.

Acid plutonic rocks are extensively developed over the southern and central tableland areas of New South Wales (see map). Many of these intrude strata of Upper Devonian age, and belong, therefore, to the

Kanimbla Epoch; none are younger, some are probably older. The close of the Ordovician was marked by pronounced orogenic movements, and no doubt extensive plutonic intrusions took place at this time. As the age of many of these occurrences is uncertain, it will be more convenient to consider all of them together. They range from acidic to intermediate in composition, and include granites, tonalites, quartz-mica-diorites, grano-diorites and quartz-porphyrries. Highly acidic granites are uncommon, the grey varieties containing hornblende and biotite being the prevailing type; some of these so-called granites are really tonalites or grano-diorites. These plutonic rocks occur in the form of bosses and batholiths, many of which are of large size and contain a considerable variety of rock types. The one which outcrops in the Kanimbla Valley may be taken as an example; at Old Hartley the rock is a porphyritic granite, light in colour, almost free from ferromagnesian minerals, and contains numerous phenocrysts of orthoclase; at Lowther, on the other hand, the rock is much more basic, contains much hornblende and biotite, is non-porphyrific, and is very dark in colour; while on Cox's River (near Delaney's) a typical quartz-mica-diorite occurs. Whether these distinct rock-types represent separate intrusions, or are due to magmatic differentiation in the magma after it had been intruded, cannot be stated until these occurrences have been systematically mapped and studied. Between Cox's River and Lowther (on the way to the Jenolan Caves) extensive

segregations of aplitic and pegmatitic granites may be seen in the road-cuttings; these are associated with the more acidic granites. A similar granite batholith in the Bathurst district outcrops over an area of at least 450 square miles.

In the north-eastern part of the State (New England) orogenic earth-movements occurred later in the Palæozoic Era than elsewhere in New South Wales, and successive igneous intrusions took place at intervals during the Carboniferous and Permo-Carboniferous Periods. The chronological succession of these intrusions was probably as follows:—

1. (?) Carboniferous.—The Dark Felspar Porphyries.
2. Carboniferous (end of).—The “Blue Granite.”
3. Permo-Carboniferous.—
 - (a) Middle of the Period—The “Sphene-Granite Porphyry.”
 - (b) Close of the Period—The Acid Granites (the Tin Granites).

The “Dark Felspar Porphyries” occur from Ballandean, in Queensland, to as far south as Armidale, and outcrop extensively around Tenterfield, Emmaville, Glen Innes, and elsewhere; they are the oldest of the New England series, but their exact age is not known. The “Blue Granite” occurs as large bosses and batholiths at many and widely separate localities, such as Tenterfield, Bolivia, and Deepwater; biotite is a constant constituent, and the rock has a bluish colour, hence its name. The “Sphene-

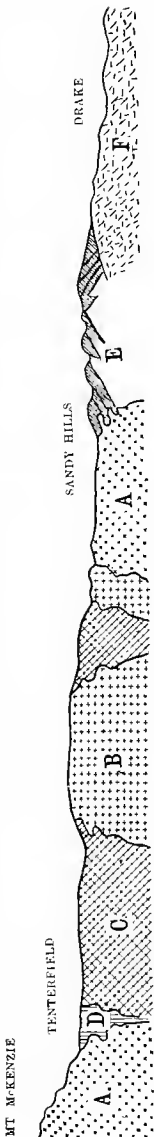


Fig. 90.

Section in New England, showing the various Plutonic Intrusions. (Andrews).

A = The "Acid Granite," B = The "Sphene-Granite-Porphry," C = The "Blue Granite," D = The Dark Porphyries,
E = Permo-Carboniferous (? Lower Marine Series), F = Carboniferous (phyllolites and tuffs).

Granite Porphyry" has an even wider distribution than the former, occurring, as it does, at intervals over an area of about 1,600 square miles, extending from Wallangarra (Queensland) to Bolivia. This rock consists of large porphyritic crystals of orthoclase, set in a matrix of quartz, felspar, and hornblende, frequently with numerous visible crystals of sphene. It contains a wonderful development of basic segregations, and makes a very handsome ornamental stone when polished; it intrudes the "Blue Granite." Large batholiths of a very acid granite, which intrudes both the "Blue Granite" and the "Sphene-Granite Porphyry," are found over the whole of New England, but with their maximum development to the north. An extensive development of greisen and pegmatite occurs about the peripheries of these acid intrusions, and with them are associated important ore deposits containing tin,

bismuth, tungsten, molybdenum, and monazite. All the abovementioned igneous rocks are intruded by a series of intermediate and basic dykes, whose age has not been determined. Regarding the evidence for the geological age of these New England plutonic rocks, the "Acid Granite" and the "Sphene-Granite Porphyry" both intrude the Lower Marine Series (Permo-Carboniferous), while the former also intrudes the latter; both also intrude the "Blue Granite," which, however, is not known to intrude any Permo-Carboniferous strata; none of these plutonic rocks intrude the Triassic strata, which occur in the eastern part of this region. Taking these facts in conjunction with what has been said about the crustal movements which affected this region in late Palæozoic times (Chapter X.), it would seem probable that the ages given above are approximately correct.

Many extensive occurrences of serpentine (altered peridotite) are found in New South Wales, whose intrusion is now definitely stated as having taken place at the close of the Carboniferous Period. The most striking example occurs in New England, and extends as a narrow belt from Bingara past Barraba, Crow Mount, and Nundle at intervals to Port Macquarie, a distance of about 200 miles. This intrudes strata of Devonian and Carboniferous age, but is not known to intrude any younger formation. Other well-known examples occur at Lucknow, near Orange (an altered andesite), and at Gundagai; these two

occurrences are probably older than those of New England, and may be provisionally referred to the Kanimbla Epoch. The occurrence of extensive intrusions of basic and ultrabasic igneous rocks which do not outcrop at the surface is implied by the occur-



Fig. 91.

Granite, Baker's Creek, New England.

rence of fragments of gabbro and peridotite in the dykes and volcanic necks of the Sydney-Blue-Mountain and Illawarra districts. These have evidently been brought upward from some deep-seated source by the material which filled these dykes and necks.

(b) *Cainozoic Intrusive Rocks*.—Extensive epeirogenic movements affected the earth's crust in Eastern Australia during this era, and these have been accompanied in places by those types of intrusion which are usually associated with such movements, viz., laccolites, sills, dykes, and necks (plugs). These intrude the Trias-Jura strata; but, as no younger sedimentary strata exist where these intrusions are found, the exact determination of their age is difficult. They include a highly interesting series of alkaline rocks which, in their composition, appear to be related to the lavas of late Tertiary age described on page 241. This series includes nepheline-syenites, tinguaite, trachytes, and bostonites. In the neighbourhood of Lue several large laccolites of tinguaite intrude the Triassic strata of that region. The rocks here consist of soda-orthoclase, nepheline, agirine, and sodalite, and are very rich in soda; they are pre-vaillingly green in colour, and make a handsome ornamental stone when polished. In the Mittagong-Bowral district numerous dykes and (?) plugs of alkaline trachyte occur; the latter will be referred to again on page 242.

In the Kiama district sills of nepheline-syenite and tinguaite intrude the Upper Coal Measures (Permo-Carboniferous); their age has not been determined, but their composition suggests that they are allied to the Tertiary alkaline rocks of other localities. Analyses are given in Table II. of some of these interesting alkaline rocks, which, as will be seen, contain from 10 to 16 per cent. of

alkalies, with very low percentages of the alkaline earths.

As stated above, they are very similar in composition to the alkaline lavas described on page 241, but whether the two series were intruded and ejected contemporaneously it is at present impossible to say.

An interesting series of basic intrusions also occurs in the eastern part of New South Wales; these have been studied in some detail in the Sydney-Blue Mountain area, and in the Illawarra district, where they occur in the form of dykes, sills, plugs, and small laccolites. For such basic rocks they contain a high percentage of alkalies, as will be seen from the analyses in Table III.

One of the most interesting of these intrusions is that which occurs at Prospect, near Parramatta; it is a (?) sill of peculiar shape containing analcite-dolerite, and intrudes the Wianamatta Shales. Interesting aplitic and pegmatitic segregation veins are found near the periphery of this intrusion, the former of which are markedly more acidic and alkaline than the parent rock, and consist mainly of albite-felspar and analcite. Of the many volcanic necks which occur in this region some are filled, wholly or partly, with basalt; these were probably points of eruption. There are others, however, which are filled with a breccia composed largely of non-igneous material, including fragments of coal, carbonaceous shale, sandstone, etc., derived from the wall rocks; such are those occurring at Hornsby, Springwood,

Missing Page

Euroka Farm, and The Basin (Nepean River). These more or less cylindrical apertures have probably been produced by the action of steam and other gases imprisoned in magma reservoirs at no great distance below the surface, which have, by their explosive energy, drilled an opening upwards through the overlying strata until escape became possible; they possessed, however, neither energy enough to clear the vent of the comminuted rock material produced in forcing their way upwards, nor to force the molten magma to the surface. The volcanic neck at Dundas, near Parramatta, which is filled partly with basalt and partly with agglomerate, contains numerous fragments (xenoliths) of basic and ultrabasic plutonic rocks embedded in the basalt; these include gabbros and peridotites, with a considerable variety of mineral composition. Similar xenoliths have been found in basic dykes as far south as Kiama, and as far west as Bowenfels; their occurrence may be taken to indicate that large basic and ultrabasic plutonic intrusions occur beneath this area, but are too deep-seated to have been revealed anywhere at the surface by denudation.

Basic dykes occur in considerable numbers in the districts adjacent to Sydney; those which outcrop along the coast, while having a general east and west strike, appear to have a radial arrangement, and to converge to a locus about 20 miles due east of Botany Bay. They range from a few inches up to 20 feet and upwards in thickness. Similar dykes in the Illawarra district intersect the Upper Coal Measures,

and have, in the case of the larger ones, done considerable damage to the coal-seams. Here also basic sills have intruded the same strata, in some cases (North Bulli) along the top of the Bulli seam, in other cases (Metropolitan Colliery) along the middle of the seam for long distances; such sills destroy the coal over large areas. Between two and three hundred of these dykes are now known.

According to Mr. G. W. Card, the dykes of the Sydney-Illawarra region may, in the light of our present knowledge, be classified as follows:—

- | | | |
|---------------------|---|---|
| 1. Lamprophyric | { | Camptonite.
Monchiquite.
Olivine Basalt. |
| 2. Non-Lamprophyric | { | Basalt.
Dolerite.
Nephelinite.
Basanite. |

This classification is based on (*a*) textural, and (*b*) mineralogical grounds, and is merely a tentative classification, because as pointed out by Mr. Card, many of the rocks included are undoubtedly representatives of the same phase of intrusion. A considerable number of these dykes have been classed as monchiquite, a lamprophyric rock. They are typically basaltic in appearance, are very dense, often show olivine, and are more or less calcareous. Under the microscope they are seen to consist of a ground mass of automorphic augite and magnetite, with a base of more or less clear, colourless isotropic material. They contain small olivine phenocrysts and some of

them are slightly felspathic, but the dominant mineral is augite. The isotropic base is considered to be primary analcite.

Some of the basalt dykes undoubtedly contain nepheline, and it is probable that this mineral will be detected in many more of them.

One of the most interesting features of the Post-Triassic dykes of this region is the frequent occurrence in them of xenoliths of basic and ultrabasic plutonic rocks. These xenoliths include various types of gabbro and peridotite often coarsely grained. One dyke at Bulli contains masses of olivine as large as an apple, and lustrous, well-cleaved hornblende, in pieces up to 6 cm. by 4 cm. in size. It would seem certain that the xenoliths and xenocrysts of this character must have come from rocks which cooled with unusual slowness under great pressure. Under the microscope their contacts with the enclosing dyke rock always show that assimilation has taken place; in the case of the gabbro xenoliths, the assimilation has been selective. The occurrence of these xenoliths is common along the coast district from Sydney to Gerringong, a length of about 65 miles, and at least as far inland as Bowenfels. In two localities (Port Kembla and Gerringong) xenoliths of granite have also been found.

Without critically discussing the origin of these xenoliths, it may be stated that they have probably been derived from very deep-seated ultrabasic plutonic rock, and that the dyke rocks in which they are embedded have been derived from the refusion of these plutonic rocks.

B.—THE VOLCANIC ROCKS.

No active volcanoes occur in New South Wales, or in any other part of Australia, at the present day; nevertheless there is abundant evidence to show that vulcanism had frequently, and for long periods of time, been an important factor in its geological history. Nearly every period belonging to the Palæozoic Era had its volcanoes, from which extensive floods of lava were poured out. The Mesozoic Era, on the other hand, appears to have been quite free from volcanic displays. In the Cainozoic Era renewed activity took place; first came great floods of basaltic lava from fissure eruptions, while later on volcanic cones developed as the result of the piling up of alkaline lavas and tuffs. These late Tertiary cones, although they have suffered considerable denudation, still remain as evidence of the great eruptions which produced them. Reference has already been made in previous chapters to the volcanic rocks associated with the strata of each of the geological periods. These occurrences will now be summarised in chronological order.

Nothing is yet known regarding the vulcanicity of pre-Palæozoic times; some of the pre-Cambrian rocks of the Barrier district may represent metamorphosed lavas and tuffs, but no detailed description of these rocks is yet available. The volcanic eruptions of the Palæozoic Era appear, in most cases, to have occurred in, or adjacent to, subsidence areas, and to have, in the main, preceded the more important crustal move-

ments. The Carboniferous eruptions, for example, appear to have been confined to the north-eastern part of the State, the only part undergoing subsidence at that period.

Cambrian Period.—Nothing is yet known of the vulcanicity, if any, of this period.

Ordovician Period.—Extensive deposits of andesitic lavas and tuffs occur, associated with the Ordovician strata of the Orange-Cadia district. These volcanic rocks have a great thickness at Forest Reefs, near Orange, and the tuffs there are crowned with angular fragments up to a foot or more in diameter. Andesitic lavas of Ordovician age have also been described from the Forbes-Parkes district. No analyses of these rocks are available.

Silurian Period.—Considerable volcanic activity took place during this period; rhyolite lavas and tuffs occur interstratified with Silurian strata at Jenolan Caves, at Bowen Park, near Orange, in the Yass district, and in the Cobar district; while andesitic lavas and tuffs occur in the Parkes-Forbes districts. The published information regarding these occurrences, however, is very scanty. Many of the rhyolites of this and the next period closely resemble quartz-porphry in the hand specimens, and are frequently mistaken for this intrusive rock.

Devonian Period.—The Silurian vulcanism continued on into the Devonian Period, at the beginning of which stupendous outpourings of acid lavas and tuffs took place in south-eastern New South Wales and north-eastern Victoria. At Taemas, in the

former State, these accumulated to a maximum thickness of 5,000 feet, while in addition the thick Lower Devonian marine strata, which overlie them, are more or less tuffaceous throughout. In the Tamworth district also volcanicity was a pronounced feature during this epoch. Spillite lavas are a very characteristic feature of the volcanicity of this region, but extensive beds of tuff, mainly intermediate in composition, also occur. During the Upper Devonian Epoch on the other hand vulcanism was, except in the Yalwal district, more or less dormant; in this locality, however, an extensive alternating series of rhyolite and basalt flows of some magnitude was poured out.

Carboniferous.—Volcanic eruptions, although confined to the north-eastern part of the State, occurred there on a grand scale throughout the greater part of this period, but particularly towards its close. In the Paterson and Clarencetown districts at least twelve distinct lava flows, as well as thick beds of volcanic ash, are interstratified with the Carboniferous strata (see Fig. 31); these lava flows, which range up to 200 feet or more in thickness, are nearly all acidic in composition (rhyolites), but some hypersthene-andesites also occur. At Pokolbin the volcanic series includes rhyolites, trachytes, and andesites erupted in that order. Extensive deposits of carboniferous rhyolites and tuffs also occur on the Drake goldfield, in northern New England, and in the neighbourhood of Bolivia and Tenterfield.

Permo-Carboniferous.—During this period vulcan-

ism was, on the whole, less pronounced and more local in its distribution than had been the case in the Carboniferous Period. During the early part of the Lower Marine Epoch several extensive basic and intermediate lava-flows were poured out in what is now the Hunter River district, while at about the same time an extensive series of andesitic lavas and tuffs accumulated in northern New England (Drake goldfield). Then followed a considerable period of rest until, towards the close of the Upper Marine Epoch, a great centre of eruption developed in the Illawarra district. Submarine volcanoes here poured out a great series of lavas and tuffs on a subsiding sea-floor; these range up to 1,000 feet in thickness, and vary from basic to intermediate in composition; they have already been described in some detail on page 112. These rocks are abnormally rich in potash, and are now called latites; they are regarded as the effusive equivalents of the intrusive monzonites occurring at Milton and other parts of the district. These eruptions continued on into the Upper Coal Measure Epoch, but on a much reduced scale, when two small basaltic flows were poured out into the Coal Measure swamps. At this time a new centre of eruption developed near Murrurundi, on the north-western margin of the coal-basin, from which basaltic lavas aggregating many hundreds of feet in thickness were poured out.

The Mesozoic Era.—No volcanic eruptions are definitely known to have occurred in New South Wales during this era. Certain beds of chocolate-

coloured shales, which belong to the Narrabeen stage of the Hawkesbury Series (Triassic), are considered to be redistributed tuffs, and have the following composition:—

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O
62.92	23.30	0.27	3.08	0.66	0.58	0.28	1.52	7.00

Whether these were produced by Triassic volcanic eruptions is not known: in any case they were formed very early in the Mesozoic era. No other volcanic rocks of Mesozoic age are definitely known to occur in New South Wales.

Cainozoic Era.—The long period of rest which characterised the Mesozoic Era now gave place to renewed volcanic activity. This resulted in the outpouring of vast floods of basaltic lavas, which filled and in many places overflowed the river channels, and thus buried hundreds of square miles of country under a covering of basalt. These sheets of basalt still form the surface rocks over large areas in the eastern part of New South Wales. There are reasons for thinking, as explained in the previous chapter, that these Tertiary basalts belong to two distinct periods of eruption—an older basalt series now represented by cappings on the tops of more or less isolated hills (residuals), which rise above the general level of the tablelands, and a younger series which over large areas forms the surface capping of the tableland itself. The former have been provisionally assigned to the Eocene Period, the latter to the Upper Miocene or

Lower Pliocene Period. These olivine-basalts (see analyses) from a petrological point of view possess no feature of special interest, but by their weathering they have produced some of the finest agricultural soils in the State. Towards the close of the Pliocene Period several isolated centres of eruption developed, from which a highly interesting series of alkaline lavas was erupted. These lavas and their associated tuffs built up groups of volcanic cones, such as the Canobolas Mountains near Orange, the Warrumbungle Mountains near Coonabarabran, and the Nandewar Mountains near Inverell. Taking the first-named as a type, they stand on the top of the tableland near Orange, adjacent to a fault (or series of faults) marking its western edge. The first eruptions brought to the surface a series of highly acid and alkaline viscous lavas, which built up a series of steep lava cones; then came great showers of volcanic ash, included in which were fragments varying up to several tons in weight. Further lava-flows followed at intervals, becoming progressively more basic, the eruptions finally closing with the outpouring of somewhat basic alkaline andesites. The order of extrusion of lavas was as follows:—

1. Alkaline rhyolites (Comendites) and quartz trachytes.
2. Alkaline trachytes.
3. Phonolitic trachytes.
4. Andesites.

The Warrumbungle and Nandewar Mountains consist of similar lavas and tuffs, as may be seen from the

analyses in Table V. In the Mittagong-Bowral district two large cones of alkaline lava occur, viz., the Gib Rock and Mount Jellore. The well-known Gib rises about 800 feet above the surrounding country, and consists of a fine-grained alkaline syenite (allied to bostonite), which consists mainly of orthoclase-felspar, and contains narrow segregation veins consisting of sanidine, hornblende, and aegirine. This rock makes an excellent building stone, and is used to a considerable extent in the buildings of Sydney. The Gib is believed to represent the denuded plug of a volcano similar to those occurring in the Warrumbungle Mountains. Mount Jellore is a similar lava cone, consisting of alkaline trachyte.

Alkaline trachytes also occur near Dubbo, and at various places in the Northern Rivers district.

Summarising the igneous rocks of New South Wales from the point of view of composition and age, we get the following:—

		Volcanic.	Intrusive.
Cambrian ...	...	None known	None known
Ordovician...	...	Intermediate	Intermediate
Silurian ...	...	Acidic to intermediate	} Acidic to intermediate
Devonian ...	...	Acidic (mainly)	
Carboniferous	...	Acidic (mainly)	Acidic mainly
Premo - Carboniferous	...	Intermediate to basic	..
Triassic ...	...	} Absent	Absent
Jurassic ...	...	
Cretaceous ...	...	
Eocene ...	...	} Basic	Basic
Miocene ...	...	
L. Pliocene	...		
Up. Pliocene	...	Acidic to basic and highly alkaline	Acidic to basic and highly alkaline

TABLE I.

ANALYSES of some Paleozoic Intrusive Igneous Rocks of New South Wales.

Age.	Name.	Locality.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O 100° C	CO ₂	Ti O ₂	P ₂ O ₅	Analyst.
Pre-Cambrian	Granite	Broken Hill	74.50	13.72	0.60	0.44	0.52	3.47	5.13	0.18	0.26	0.17	0.27	J. C. H. Mingaye
	Gneiss	Coona District	75.27	11.77	1.95	0.70	0.80	1.56	3.08	0.15	0.70	0.60	0.19	U. B. Gurney
	Aplitic Granite	Bowenfels	77.28	11.90	1.30	0.18	0.10	0.80	3.01	5.26	0.07	0.38	0.12	Do.
	Granite	Braidwood	69.38	12.56	2.40	2.25	1.47	3.72	2.77	3.75	0.09	1.05	0.52	H. P. White
	Biotite-Granite	Kimbra	65.94	13.10	1.20	2.31	2.53	1.48	3.09	3.73	0.11	0.80	0.55	Do.
	Hornblende-Biotite Granite.	Bathurst	66.69	17.03	3.15	0.69	2.50	1.82	1.21	6.26	...	...	tr.	J. C. H. Mingaye
Devonian (close of) or Early Carboniferous	Quartz-Porphyr	Barrenjuck	69.24	12.88	0.20	4.05	2.21	3.10	2.94	3.66	0.06	0.80	0.55	H. P. White
	Quartz-Porphyr	Woolandilly River, Wombeyan mts.	66.06	13.25	1.10	3.69	2.27	4.83	2.16	2.77	0.30	0.94	0.70	J. C. H. Mingaye
	Quartz-Porphyr	Mount Lambie	61.54	16.79	3.48	2.22	1.95	5.43	4.78	2.38	0.35	...	0.55	A. Liversidge
	Quartz-Felsite	Yerranderr	63.54	15.07	1.90	3.51	2.82	3.10	2.49	3.15	0.22	2.40	0.73	H. P. White
	Granite	Moruya	67.56	16.39	1.25	1.86	1.48	5.08	3.54	1.77	...	...	1.34	A. Liversidge
	Porphyritic-Diomite	Milton District	51.11	17.70	3.69	5.13	3.43	6.51	3.97	3.25	0.52	2.41	0.65	H. P. White
	Granite-Diorite	Tullong	59.24	15.61	1.55	6.25	3.63	6.65	2.88	2.06	0.57	0.39	1.08	G. J. Burrows
	Quartz-Porphyr	Coahar District	78.16	11.01	0.10	0.63	0.15	0.30	0.36	7.97	0.21	0.17	0.32	W. A. Greig
	Blue Granite	Tenterfield	65.36	16.37	1.80	2.68	1.81	3.82	3.40	3.75	0.09	0.33	0.36	J. C. H. Mingaye
	Sphene-Granite-Porphyr	Wilson's Downfall	64.29	16.94	2.00	2.41	2.03	1.56	4.00	2.76	0.14	0.47	0.39	Do.
Carboniferous	Sphene-Granite-Porphyr	Waltcha Road	69.14	14.74	0.70	1.98	1.58	3.14	3.36	4.43	0.18	0.38	0.36	W. A. Greig
	Diorite	Hillgrove	55.05	14.15	1.80	5.31	8.07	0.36	2.82	0.22	1.46	0.57	0.06	J. C. H. Mingaye
Permian-Carboniferous.	Acid Granite	Bolivia	75.78	12.42	0.55	1.98	0.50	1.06	3.20	1.60	0.14	0.44	0.29	Do.
	Aplitic Granite	Tenterfield	74.69	14.49	1.10	0.45	0.14	0.92	3.29	4.85	0.18	0.56	0.14	Do.

TABLE II.

ANALYSES of Intrusive Alkaline Igneous Rocks of (?) Tertiary Age.

Name.	Locality.	Mode of Occurrence.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O + H ₂ O	TiO ₂	P ₂ O ₅	Analyst.	
Nepheline Syenite	Jamberoo	Sill	51.48	17.07	1.90	4.95	1.10	3.04	5.65	5.22	0.67	3.25	1.16 (CO ₂ +47.)	0.42	H. P. White
Tingnaitite	"	"	55.82	20.19	3.70	1.17	0.25	1.02	9.57	5.60	0.45	1.30	0.01	0.07	J. C. H. Mingaye
Pulaskite Porphyry	Nanlewar Mountains	"	58.90	16.48	2.98	3.35	0.78	2.78	4.09	6.05	0.82	0.34	1.47	...	H. I. Jenson
Trachyte	Mount Jellore, Bowral	Plug (?)	66.68	14.63	2.18	2.31	0.30	1.88	6.12	4.02	0.38	0.83	0.20	0.28	Mawson & Taylor
Syenite (Bostonite)	"The Gil," Bowral	Plug (?)	55.16	16.67	2.36	7.31	0.56	2.30	5.65	6.97	0.85	0.88	0.60	0.38	"
Tingnaitite	Mount Kosciusko	Dyke	51.98	20.61	4.08	1.32	0.38	1.12	11.69	4.42	0.32	3.29	...	...	F. B. Guthrie
"	Bald Mount, Barigun	Laccolite	54.44	20.01	4.10	1.89	0.36	1.26	9.88	5.77	0.34	1.94	trace	0.16	H. P. White
"	Dairy Mount	"	52.35	19.87	2.70	2.97	0.38	1.76	9.69	4.23	0.34	5.00	0.06	0.15	J. C. H. Mingaye
"	North Jimmy	"	54.82	20.58	2.89	0.36	0.20	0.44	10.60	4.91	0.32	4.13	...	0.04	"
"	The Pinnacle, Lue	"	53.30	22.19	3.58	1.55	0.24	1.36	9.73	5.74	0.38	1.38	...	0.08	"

TABLE III.

ANALYSES of Basic Intrusive Rocks of Tertiary Age.

Name.	Locality.	Mode of Occurrence.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O + H ₂ O	T ₁ O ₂	P ₂ O ₅	CO ₂	Analyst.	
Monchiquite ...	Kiama ...	Dyke ...	39.35	11.00	3.32	7.38	9.82	12.66	2.00	1.77	1.28	3.82	0.64	4.04	H. P. White	
Do. (Fourehite)	Wollongong ...	"	41.72	16.87	5.91	3.87	4.23	10.32	4.99	2.73	0.45	3.67	0.85	...	J. C. H. Mingaye	
Nepheline Monchiquite,	Patty ...	"	41.38	13.09	5.80	7.07	8.30	9.92	4.23	0.72	0.52	4.44	0.77	...	H. P. White	
Monchiquite ...	"	"	43.32	14.97	3.50	7.11	10.51	9.78	3.33	0.78	0.44	3.94	0.48	...	J. C. H. Mingaye	
Essexite ...	Jellore Creek, Bowral	(?)	46.22	9.33	5.85	7.39	3.08	10.80	3.21	1.80	0.94	2.30	0.80	4.46	Mawson & Taylor	
Dolerite ...	Prospect, near Sydney	Sill	43.06	16.31	5.40	7.61	5.49	9.37	3.12	1.07	1.16	2.93	0.32	1.36	J. C. H. Mingaye	
Basalt ...	Dundas "	Volcanic Neck.	45.88	17.16	3.03	7.57	6.26	7.20	4.08	1.78	0.88	3.17	0.19	...	H. P. White	
Dolerite ...	Long Reef, Sydney	Dyke	41.22	15.00	4.96	8.95	6.26	9.96	2.21	2.02	0.68	1.87	1.44	0.37	7.12	"
Analcite-Basalt	Bondi, Sydney	" (?)	43.39	16.07	3.47	8.80	7.30	8.79	3.30	2.17	0.29	2.67	0.41	0.39	J. C. H. Mingaye	
"	Fernhill, Canterbury	"	41.10	14.82	2.35	10.28	9.43	10.56	3.94	1.28	0.39	2.31	0.19	0.26	"	
"	Luddenham ...	"	43.54	15.61	3.20	8.64	9.16	8.88	3.44	2.10	0.92	2.56	1.81	0.40	0.21	H. P. White
Olivine Basalt	Hurstville, Sydney	"	42.28	14.70	3.96	9.24	9.15	9.98	3.13	1.99	0.14	1.34	0.39	0.94	J. C. H. Mingaye	
Dolerite ...	Guildford	"	38.12	14.11	3.58	7.43	6.91	11.40	2.23	1.16	0.38	2.71	1.12	0.40	0.60	H. P. White
Olivine Basalt	Chandon Park	"	46.51	15.27	2.50	8.92	8.40	9.12	3.12	1.17	0.22	1.21	0.33	0.61	J. C. H. Mingaye	
"	Reokwood	"	44.54	16.44	2.00	9.75	10.82	9.16	3.04	1.23	0.25	1.53	0.80	0.44	"	

TABLE IV.

ANALYSES of some Palaeozoic Volcanic Rocks of New South Wales.

Age.	Name.	Locality.	SiO ₂	Al ₂ O ₃	Fe ²⁺ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O 100° C.	H ₂ O 100° C + C	TiO ₂	P ₂ O ₅	Analyst.
Silurian	Rhyolite (1)	Jenolan Cambesley	74.18 73.33	11.15 12.43	0.90 0.10	1.31 2.43	0.62 0.50	1.35 0.98	1.00 2.71	5.86 5.66	0.15 0.00	1.27 1.41	0.25 0.23	0.15 0.11	W. G. Stone H. P. White
Lower Devonian	"	Taemas, Mur- rumidgee River.	63.94	16.77	1.80	1.98	1.61	0.92	5.34	4.97	...	...	...	...	H. P. White
"	Tuff	Tamworth	56.06	18.36	4.40	2.68	4.58	6.06	3.71	0.66	0.28	2.50	...	0.19	W. N. Benson
"	Spillite (2)	Nundle	48.22	14.82	0.56	9.25	5.58	8.71	4.95	0.44	2.64	0.15	2.68	0.23	"
Carboniferous	Rhyolite	Tenterfield	73.68	15.06	0.68	0.54	0.26	0.54	3.36	5.45	0.18	0.16	0.11	0.28	J. C. H. Mingaye
"	Rhyolite Glass	Gloucester	70.62	11.54	1.20	0.18	0.26	1.72	3.52	1.45	2.42	7.24	...	...	W. A. Greig
"	"	Bulladeah	71.35	12.80	0.80	0.36	0.13	0.68	2.24	3.54	1.87	6.54	...	...	"
"	Soda Rhyolite	Faddy's Hill	75.06	14.21	1.31	0.27	0.69	0.42	6.88	0.58	0.56	0.62	...	...	"
"	Rhyolite	Mt. Bright, Pokolbin.	77.82	11.46	0.30	0.09	0.23	0.22	0.86	7.19	0.35	1.40	...	...	J. C. H. Mingaye
Perno- Carboniferous— a. Lower Marine Epoch.	Olivine Basalt	Raymond Terrace	50.04	15.57	2.60	6.08	7.99	10.89	2.98	0.26	0.45	1.39	1.76	0.24	H. P. White
"	Basalt	West Maitland	48.74	16.75	6.25	2.97	5.12	7.20	4.75	1.39	0.65	4.29	1.12	0.38	"
"	Basalt (Blow-hole Flow).	Kiama District	51.92	15.58	5.00	4.68	4.09	7.72	3.38	2.56	1.19	1.35	1.20	0.54	J. C. H. Mingaye
b. Upper Marine Epoch.	Basalt (Bumbo Flow)	"	55.19	16.18	3.52	3.04	3.04	4.68	5.09	4.10	0.99	1.75	0.89	0.59	"
"	Porphyritic Basalt	Port Kembla	52.72	16.19	4.80	4.14	4.12	8.10	3.31	2.45	0.92	1.56	1.20	0.48	H. P. White
"	Trachyte	Illawarra Dist.	51.07	17.52	4.10	5.40	2.27	5.44	3.31	5.53	1.02	2.50	0.80	0.88	"
"	"	Kiama District	58.82	14.78	3.90	3.24	2.26	3.08	4.67	4.70	0.81	1.36	1.78	0.58	J. C. H. Mingaye
"	Dolerite (Saddleback Flow).	"	52.48	17.32	4.36	5.04	3.65	7.66	3.43	2.53	0.59	1.61	0.74	0.42	H. P. White
c. Upper Coal Mea- sure Epoch.	Dolerite (Minnamurra Flow)	"	51.32	18.82	4.50	2.97	3.58	6.42	3.97	3.31	0.87	2.89	2.72	0.42	"

(1) CO₂ 2.00 (2) Mn O. 2.23.

TABLE V.

ANALYSES of Tertiary Alkaline Lavas of New South Wales.

Name.	Locality.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O 100° C	H ₂ O 100° C +	TiO ₂	P ₂ O ₅	Analyst.
Arfvedsonite-Comendite	Canoblas Mountains ...	72.06	13.86	1.90	0.19	0.18	5.84	3.69	0.33	0.21	0.12	0.06	H. P. White
Riebeckite-Comonilite ...	"	69.23	14.58	2.54	0.30	0.44	6.82	3.95	0.94	0.13	...	...	H. I. Jenson
Phonolitic Trachyte ...	"	57.39	16.88	1.09	1.01	3.16	6.71	5.86	0.49	0.11	1.11	...	"
Comonilite ...	Warrumbungle Mountains ...	74.42	12.36	0.31	0.42	0.30	3.22	5.07	2.22	2.10	...	...	J. C. H. Mingaye
Arfvedsonite Trachyte ...	"	63.90	16.74	1.72	0.06	0.09	6.35	5.77	0.27	0.43	0.25	...	H. I. Jenson
Ægirine Trachyte ...	"	63.82	17.85	2.75	0.06	0.59	7.13	5.51	0.66	0.20	0.25	...	"
Nosean-Phonolite ...	"	60.32	18.32	3.55	0.01	1.12	7.01	6.25	0.35	1.31	0.25	...	"
Trachy-Andesite ...	"	58.35	17.04	2.80	0.57	2.49	4.51	6.39	0.59	1.28	0.76	...	"
Orthoclase Basalt ...	"	51.88	14.20	3.72	4.62	6.36	3.93	3.27	0.58	1.44	3.54	trace	"
Trachyte ...	Nandewar Mountains ...	64.63	16.55	2.93	0.16	0.46	5.23	6.11	1.05	1.35	0.58	...	"
Phonolite ...	"	61.27	16.60	2.59	0.39	1.93	4.25	6.31	0.64	0.36	1.02	...	"
Phonolitic Trachyte ...	"	51.98	22.46	2.48	0.83	4.63	3.66	3.93	1.08	2.06	1.71	...	"
Quartz Trachyte ...	Parish of Dungeary, near Dubbo	67.68	13.99	3.20	0.34	0.84	5.30	4.87	0.65	1.05	0.20	0.04	H. P. White
Ægirine Trachyte (? intrusive)	Mount Jellore, near Miffa- group	66.68	14.53	2.18	0.30	1.88	6.12	4.02	0.38	0.83	...	0.28	D. Mawson
Syenite (? intrusive)	Gib Rock, near Mittagong ...	55.16	16.67	2.36	0.56	2.30	5.05	6.97	0.85	0.88	0.60	0.38	"

TABLE VI.

ANALYSES of some Tertiary Basic Volcanic Rocks of New South Wales.

Rock-name.	Mode of Occurrence.	Locality.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O 100° C	H ₂ O 100° C +	TiO ₂	P ₂ O ₅	Analyst.
Nepheline Dolerite	(?) Flow or Neck	Mount Madderula	45.25	15.13	1.80	8.80	10.24	10.98	3.36	1.22	0.00	1.21	1.52	0.32	H. P. White
" Basalt	Flow	Mount Molong	49.82	17.53	4.30	7.11	3.02	5.26	5.90	2.55	0.30	1.31	2.04	0.88	"
Olivine Basalt	"	Mount Tomah	46.42	17.42	3.70	7.45	6.61	8.56	3.61	1.80	0.34	1.52	1.88	0.87	J. C. H. Mingaye
"	"	Robertson	44.57	15.30	3.20	7.83	10.04	10.00	1.94	1.39	1.00	3.21	1.01	0.41	"
"	"	Woodlands, Bowral.	43.31	16.68	2.31	9.00	10.56	7.95	2.94	0.97	0.88	1.72	2.20	0.65	D. Mawson
"	"	Orange	48.92	14.87	3.99	7.44	5.73	7.26	3.42	1.80	0.82	1.56	2.78	0.59	J. C. H. Mingaye
"	"	Bathurst	44.07	21.38	2.82	5.99	9.58	10.24	2.70	1.03	...	...	trace	0.22	"
"	"	Hill End	44.06	13.37	2.10	8.01	13.84	8.88	3.15	2.16	0.23	1.75	1.60	0.57	H. P. White
"	"	Cordeaux	51.38	15.18	7.30	3.06	4.03	7.07	3.10	3.53	0.87	2.56	0.90	0.61	W. G. Stone
Tachlyte	"	Inverell	53.86	15.41	1.50	11.51	3.60	7.18	3.04	1.24	0.44	1.10	0.36	0.35	W. A. Greig

GLOSSARY

Actinolite Shale.—A metamorphosed shale containing the mineral actinolite. The latter is a bright green mineral, closely allied to hornblende in composition and physical characters. It usually occurs in columnar or fibrous aggregates, and is a product of metamorphism.

Alluviation.—The deposition of mechanical sediments by rivers anywhere along their courses.

Amphibolite.—A metamorphic rock consisting predominantly of hornblende (amphibole) with small amounts of plagioclase felspar. It commonly results from the metamorphism of basic igneous rocks, but may also be produced by the alteration of impure limestones, shales, etc.

Arkose.—A fragmental sedimentary rock consisting of incompletely decomposed fragments of granite.

Arkose Sandstone.—Somewhat similar to arkose, but with a preponderance of sand.

Bathylith.—The largest known type of plutonic intrusion—it may be upwards of 100 miles in diameter. It cuts across the bedding planes of the invaded formation, and its contacts therewith are usually steep. Many granite intrusions are of this type.

Boss.—A plutonic intrusion similar to bathylith, but typically smaller in size.

Bostonite.—An igneous rock of intermediate composition, allied to nepheline-syenite. It is a fine-grained, light-coloured, compact rock occurring in small intrusions. The essential constituent is an alkali-felspar (orthoclase, microcline, anorthoclase); a small quantity of biotite or hornblende may be present.

Chiastolite Slate.—A slate containing a considerable amount of the mineral chiastolite. The latter is a variety of the mineral andalusite, containing very numerous dark opaque inclusions with a characteristic symmetrical arrangement. Andalusite is a silicate of alumina; like chiastolite, it is a common product of metamorphism in sedimentary rocks rich in alumina.

Comendite.—A light-coloured volcanic rock, acidic in composition, and highly alkaline. It consists predominantly of sanidine with a fair amount of quartz, and contains also a soda-bearing amphibole (riebeckite or arfvedsonite). It much resembles trachyte in land specimens.

Cryptogamous Flora.—An assemblage of plants living in a particular area (or which had lived in a particular area, in the case of fossil floras), and which belonged to that division of the Vegetable Kingdom known as the Cryptogams (flowerless plants).

Epeirogenic Earth Movements.—A movement of the earth's crust in a vertical direction, either upwards or downwards. Such a movement will affect large areas simultaneously, and range up to many

thousands of feet in amount; but no important folding of the strata involved results. The word means "continent-making."

Epicontinental Sea.—A shallow sea overlying part of a continental platform as distinct from a true ocean basin. Such shallow seas occur around the margins of all the continents to a greater or lesser extent, and extend out to the 100 fathom line, which may be taken as the margin of a continent. The Gulf of Carpentaria is a typical example of an epicontinental sea.

Faceted Boulders.—Boulders of hard rock which have been dragged along their beds by glaciers, and have thus had their sharper edges ground down or bevelled, until finally the boulder possesses a number of flat faces at the intersection of which are rounded edges. The flat faces are frequently striated. Such features would not be possessed by ordinary waterworn boulders, which tend to become more or less spherical.

Fault Block.—A block of the earth's crust having its surface at a different elevation from that of the immediately surrounding portions, from which it is separated by faults. Such a fault-block may have its surface level, gently inclined, or even highly tilted.

Fissure Vein.—An ore deposit, tabular in form, occurring along a line of faulting; an open space between the walls of the fault has been subsequently filled by the deposition of mineral matter from aqueous solution. Fissure veins are narrow as compared with their extension horizontally and in depth.

Grano-diorite.—A plutonic igneous rock which is like a granite in every respect except that plagioclase felspar is present in much larger quantity than orthoclase felspar. In a normal granite the reverse is the case.

Greisen.—A granitoid rock consisting of quartz and muscovite, occurring at or near the periphery of a granite intrusion. It represents part of the granite itself which has been modified by magmatic waters during the final stage in the solidification of the granite, so that the felspar has been replaced by quartz and muscovite.

Littoral Deposits.—Sedimentary deposits which have accumulated in the shallow waters near the margin of the land, and consisting mainly of pebbles, gravel, sand, etc.

Magmatic Differentiation.—That process whereby the constituents of a molten magma separate from one another during consolidation, the different constituents migrating to different parts of the intrusion and forming different rock types. The most common case is that in which the more basic constituents migrate to the margin of the intrusion, where they consolidate into a relatively basic rock, leaving a more acid type to crystallise in the central part of the intrusion.

Metasomatic Replacement.—The replacement, molecule by molecule, of one mineral substance by another, the latter being in aqueous solution. The original mineral is taken into solution and carried

away, the new substance being deposited in its place. As an example we have the complete replacement of slate by metallic sulphides.

Metasomatism.—Same as metasomatic replacement.

Meteoric Forces.—Natural forces which operate upon and modify the surface of the earth, such as the atmosphere, rain, running water, etc.

Monadnock.—An isolated hill or mountain, the remains of a once-existing tableland, the other portion of the tableland having been removed by denudation.

Orogenic Earth Movements.—Lateral or tangential movement in the earth's crust whereby certain regions are subjected to compression, and as a result the strata involved are folded and faulted. The word means "range-making."

Pelagic Fauna.—The assemblage of animals which live in the surface waters of the ocean, as distinct from those which live on the sea-bottom. They are all essentially free-swimming organisms.

Peridotite.—A plutonic igneous rock belonging to the ultra-basic group, and consisting very largely of the mineral olivine.

Persistent Horizon.—A particular bed or stratum which extends over a large area, throughout which it maintains certain distinctive lithological characters by which it can be readily recognised.

Phyllite.—A metamorphic rock consisting of a fine-grained schistose aggregate of quartz and mica; it is finer-grained than the typical mica-schist.

Piedmont Plain.—An extensive alluvial plain developed along the margin of a mountain range or tableland. Each of the rivers flowing from the elevated region deposits alluvium where it leaves the high land; the deposits of adjoining streams eventually unite and thus form a continuous alluvial plain.

Porphyrite.—A porphyritic aphanitic igneous rock occurring in relatively small intrusions, and having a mineral composition similar to that of diorite. It usually contains numerous crystals of plagioclase felspar.

Regolith.—The mantle of more or less decomposed and disintegrated rock-material which overlies most of the surface of the land, and which has been produced by weathering.

Rejuvenated Streams.—Streams which, by a comparatively recent elevation of the region in which they occur, have had their grades very much steepened. With the increased power thus obtained they have cut down their channels and entrenched themselves along their old courses in the newly-elevated land.

Rift Valley.—A relatively long and narrow depression of the earth's surface resulting from the occurrence of a narrow fault-block between two higher fault-blocks.

Saddle-Reef.—A saddle-shaped ore body formed by the filling of a saddle-shaped cavity between the bedding planes of folded strata along the cap of an anticlinal fold.

Senkungsfeld.—(See Rift Valley).

Shear Zone.—A line of faulting along which the rocks on one or on both sides of the fault plane have been sheared, shattered and fissured.

Sillimanite Schist.—A schistose metamorphic rock containing the mineral sillimanite, together with quartz, mica, etc. Sillimanite is a white, silky, fibrous mineral consisting of a silicate of alumina.

Terrigenous Sediments.—Sediments consisting of fragmental material derived from the waste of the land, such as mud, sand, gravel, etc.

Tonalite.—A plutonic igneous rock allied to diorite, but differing from it in containing a fair amount of quartz. Intermediate between a diorite and a granodiorite.

Tremolite.—A white to grey mineral occurring as columnar or fibrous crystals allied to hornblende; one of the members of the amphibole group of minerals. It is a silicate of lime and magnesia, and is a product of metamorphism, particularly in limestones.

Wollastonite.—A white fibrous mineral formed in limestones by contact metamorphism; it is a silicate of lime.

Xenolith.—A fragment of one kind of rock occurring in another and foreign to it, as for example a piece of granite embedded in the basalt of a basalt dyke. In such a case the granite must be older than the basalt, and must have been formed originally under quite different conditions.

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